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NTRACTING for FOREST AERIAL PHOTOGRAPHY in the UNITED STATES

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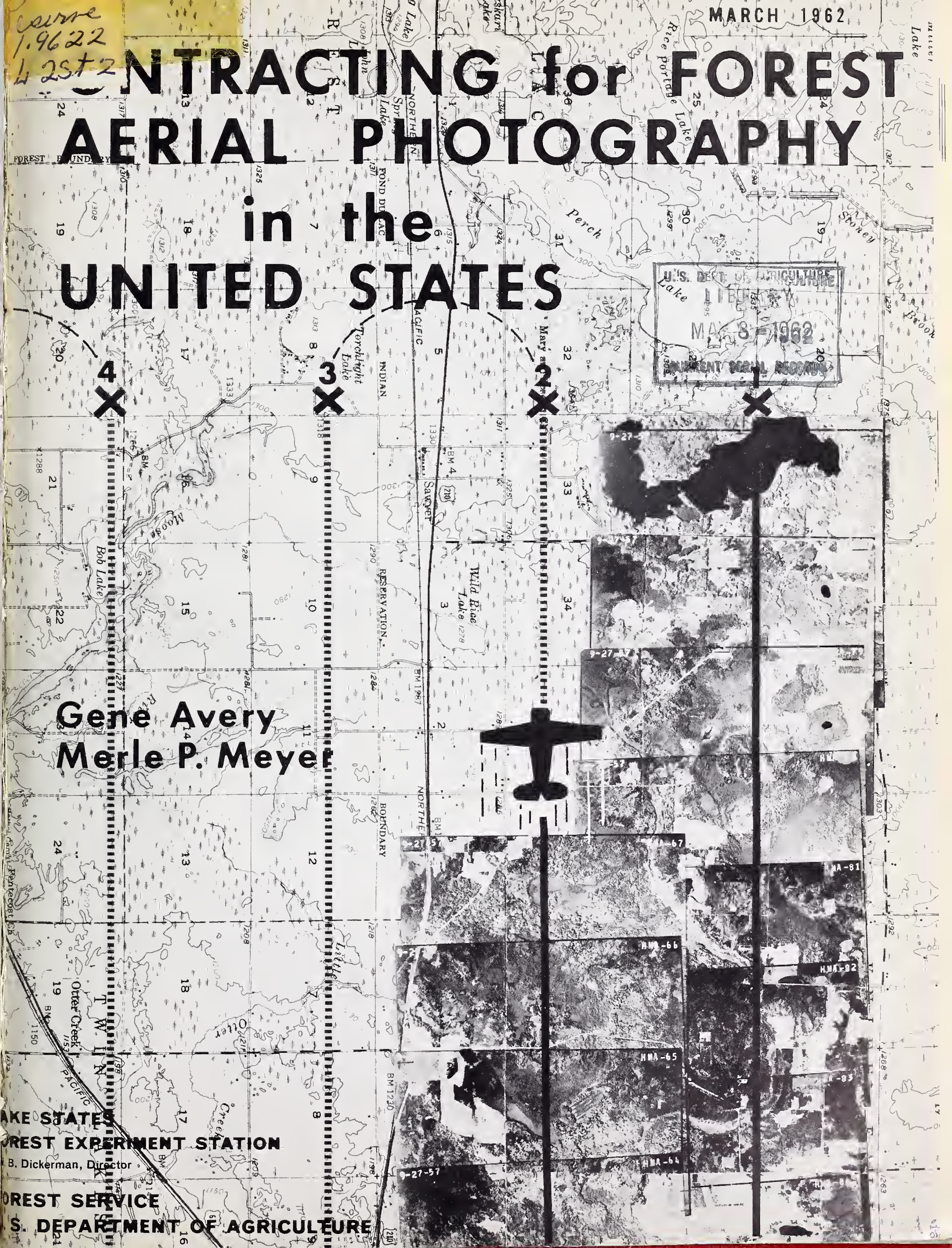

Gene Avery
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AKE STATES
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FOREWORD

The accuracy of information extracted through airphoto interpretation is largely dependent on the kind and quality of the photography. Persons responsible for obtaining forest resource photography must, therefore, be well informed on contract specifications in order to get the "best buy" for their photo dollar.

This publication, prepared by forestry staff members at the Michigan State University and the University of Minnesota, translates the technical subject of aerial photo procurement into practical and understandable terms. The Lake States Station, which worked with the authors in previous airphoto research (Station Paper 78), is publishing this report as a contribution in this joint effort.

The authors wish to express their appreciation to the following companies for providing technical assistance and illustrative materials:

Abrams Aerial Survey Corporation — Lansing, Michigan

Aero Service Corporation — Philadelphia, Pennsylvania

Mark Hurd Aerial Surveys, Inc. — Minneapolis, Minnesota

CONTENTS

INTRODUCTION 1

PRELIMINARY DECISIONS 2

  Selection of the Photographic Scale 2

  Importance of Camera Focal Length 4

  Panchromatic Versus Infrared Film 6

  Season of Photography 9

  Summing Up the Cost Factors 10

FLIGHT PLANNING 12

  Basic Information 12

  Items to be Computed 12

  Calculations 12

SELECTING AN AERIAL SURVEY FIRM 15

ISSUING BID INVITATIONS 16

A SAMPLE CONTRACT FOR AERIAL PHOTOGRAPHY 18

INSPECTING THE FINISHED PRODUCT 25

LITERATURE CITED 34

APPENDIX: GLOSSARY OF PHOTOGRAMMETRIC TERMS 35

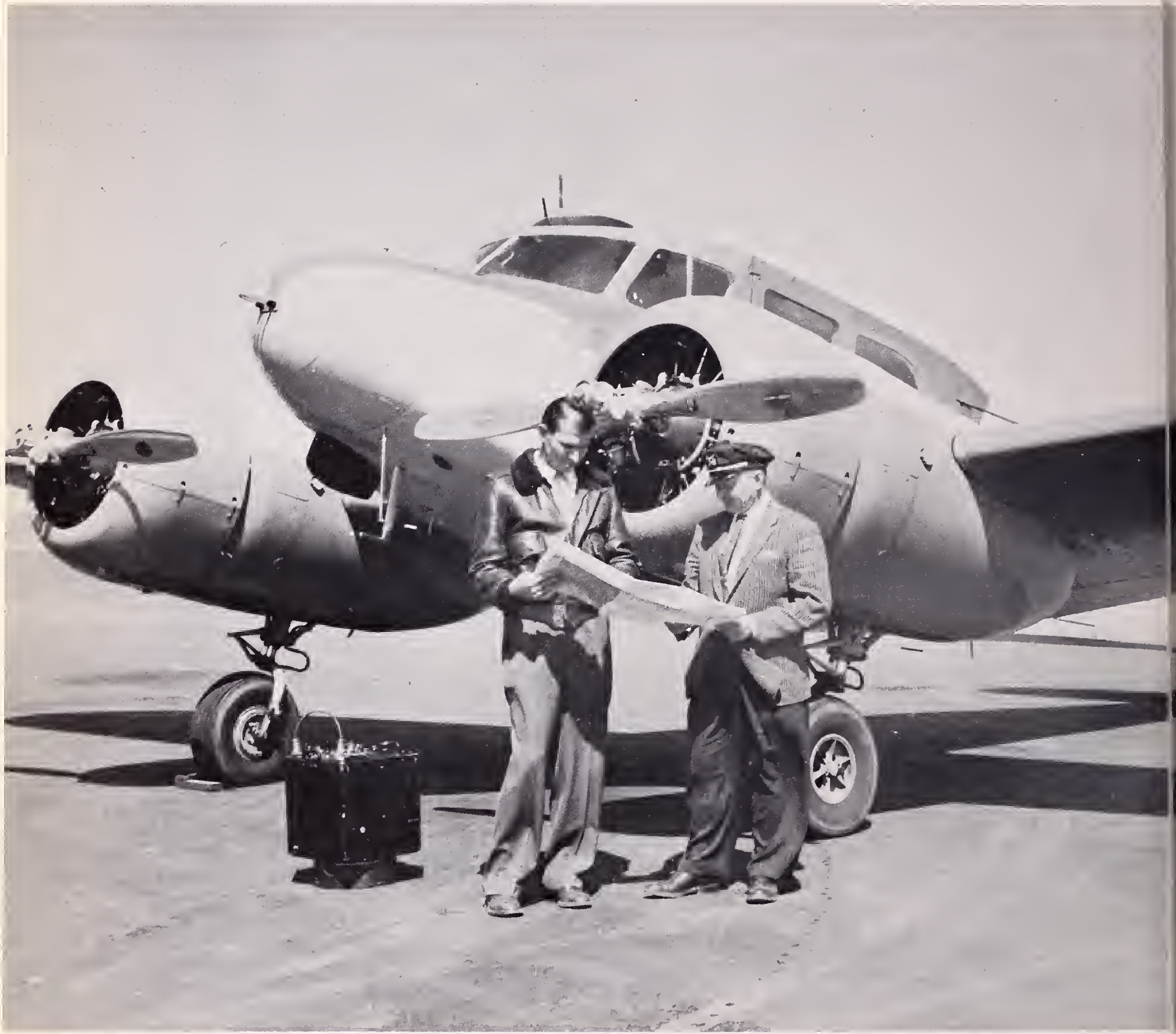

FIGURE 1. — Pilot and aerial photographer reviewing flight map prior to a photographic mission. The Twin Cessna shown cruises at an airspeed of about 140 knots. On the ground is a Fairchild T-5 aerial camera. (Courtesy of Abrams Aerial Survey Corporation.)

3

CONTRACTING for FOREST AERIAL PHOTOGRAPHY in the UNITED STATES

by GENE AVERY and MERLE P. MEYER

INTRODUCTION

Although many foresters continue to rely on prints of existing aerial photographs for mapping and stand-classification work, there is an increasing interest in the purchase of new photography taken specifically for forestry purposes (fig. 1). This bulletin was prepared to assist persons with a minimum of photogrammetric training in the procedures of buying contract photography from aerial survey companies.

In return for an investment that may amount to many thousands of dollars, the forest manager rightfully expects to obtain high-quality prints that are especially suited for the interpretation of vegetation and physiographic features. Realizing that such photography may require different specifications from those adopted by geologists, highway engineers, or topographic mappers, he must obtain reliable answers to such questions as:

a. What photographic scale will best serve my needs?

b. What combination of film, filter, and season should be specified?

c. How much will new photography cost?

d. How can a reputable aerial survey firm be located?

e. What is included in a good aerial photographic contract?

f. What techniques can be employed to determine whether the photographs purchased adequately meet the original specifications?

This report attempts to supply answers to these and other questions that may confront the forest administrator or purchaser of new aerial photography. The basic procedures outlined are generally applicable throughout the United States.

Unless otherwise noted, all recommendations are concerned with vertical black-and-white aerial photography involving 100-percent stereoscopic coverage, for this is most often desired by forestry organizations. Although photographic contracts are discussed in detail, the highly technical aspects of aerial camera calibration, lens- and film-resolution qualities, and most legal specifications have been excluded. These items are extensively treated in pages 197-270 in the *Manual of Photogrammetry (1)*.[1]

To assist the reader not entirely familiar with photogrammetric terms, a glossary is given in the Appendix.

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[1] *Italicized numbers in parantheses refer to Literature Cited, p. 34.*

PRELIMINARY DECISIONS

Before flights can be planned or bid invitations issued, certain factors must be considered. These are (1) scale selected and size of area covered, (2) camera focal length, (3) film-filter combination, and (4) time of year for photography. Except for camera focal length, these are also important cost factors. Each of these items is discussed below, and then their effect on cost factors is summarized briefly.

Selection of the Photographic Scale

In aerial photographic contracts, the term "scale" always refers to the nominal scale of the film negative. Photographic scales are commonly expressed as representative fractions, such as 1:10,000. This method of expression may also be termed the "natural scale." Conversions from representative fractions to other common units of measurement are given in table 1.

Photographs taken for forestry purposes ordinarily range between scales of 1:20,000 (1,667 feet per inch) and 1:7,920 (660 feet per inch). While these restrictions are not absolute, they have a logical basis. Many foresters have access to only a minimum of specialized interpretation equipment; with such minimum equipment, desired information on forest types and stand-size classes cannot be efficiently obtained from photos

TABLE 1. — *Scale conversions for vertical aerial photographs*[1]

Representative fraction (scale)	Feet per inch	Chains per inch	Inches per mile	Acres per square inch	Sq. mi. per square inch
(1)	(2)	(3)	(4)	(5)	(6)
1: 7,920	660.00	10.00	8.00	10.00	0.0156
1: 8,000	666.67	10.10	7.92	10.20	0.0159
1: 8,400	700.00	10.61	7.54	11.25	0.0176
1: 9,000	750.00	11.36	7.04	12.91	0.0202
1: 9,600	800.00	12.12	6.60	14.69	0.0230
1:10,000	833.33	12.63	6.34	15.94	0.0249
1:10,800	900.00	13.64	5.87	18.60	0.0291
1:12,000	1,000.00	15.15	5.28	22.96	0.0359
1:13,200	1,100.00	16.67	4.80	27.78	0.0434
1:14,400	1,200.00	18.18	4.40	33.06	0.0517
1:15,000	1,250.00	18.94	4.22	35.87	0.0560
1:15,600	1,300.00	19.70	4.06	38.80	0.0606
1:15,840	1,320.00	20.00	4.00	40.00	0.0625
1:16,000	1,333.33	20.20	3.96	40.81	0.0638
1:16,800	1,400.00	21.21	3.77	45.00	0.0703
1:18,000	1,500.00	22.73	3.52	51.65	0.0807
1:19,200	1,600.00	24.24	3.30	58.77	0.0918
1:20,000	1,666.67	25.25	3.17	63.77	0.0996
1:20,400	1,700.00	25.76	3.11	66.34	0.1037
1:21,120	1,760.00	26.67	3.00	71.11	0.1111
1:21,600	1,800.00	27.27	2.93	74.38	0.1162
1:22,800	1,900.00	28.79	2.78	82.87	0.1295
1:24,000	2,000.00	30.30	2.64	91.83	0.1435
1:25,000	2,083.33	31.57	2.53	99.64	0.1557
1:31,680	2,640.00	40.00	2.00	160.00	0.2500
Method of calculation	$\frac{\text{RFD}}{12}$	$\frac{\text{RFD}}{792}$	$\frac{63{,}360}{\text{RFD}}$	$\frac{(\text{RFD})^2}{6{,}272{,}640}$	$\frac{\text{Acres/sq. in.}}{640}$

[1] *Conversions for scales not shown can be made from the relationships listed at the bottom of each column. Using the scale of 1:7,920 as an example (col. 1, line 1), the number of feet per inch is computed by dividing the representative fraction denominator (RFD) by 12 (no. of inches per foot). Thus, 7,920÷12 =660 feet per inch (col. 2). By dividing the RFD by 792 (inches per chain), the number of chains per inch is derived (col. 3). Other calculations can be made similarly. Under column 4, the figure 63,360 represents the number of inches in one mile; in column 5, the figure 6,272,640 is the number of square inches in one acre; and in column 6, the number 640 is acres per square mile.*

taken at scales smaller than 1:20,000. Actually, there is often little incentive for specifying the 1:20,000 scale itself, for low-cost prints at this scale may be purchased from public agencies for most of the United States (*3*).

At the opposite extreme, scales larger than 1:7,920 can rarely be economically justified by photo interpreters. When the photographic scale is doubled, as from 1:15,840 to 1:7,920, *four times* as many prints are required to cover the same area — with a significant increase in cost. Furthermore, interpreters have yet to prove conclusively that their P. I. (photo interpretation) results can be significantly improved merely by resorting to larger and larger photographic scales. In special cases, such as forest insect surveys, scales as large as 1:5,000 to 1:500 may well be defended, but the bulk of forest photo-interpretation work does not fall within this category. Figure 2 illustrates the contrast in image sizes found on three scales of photography of the same area.

Despite the scale limitations defined, a wide latitude of choices is open to the forest administrator. The U. S. Forest Service employs scales of 1:15,840 (1,320 feet per inch) and 1:12,000 (1,000 feet per inch) for mapping and inventory

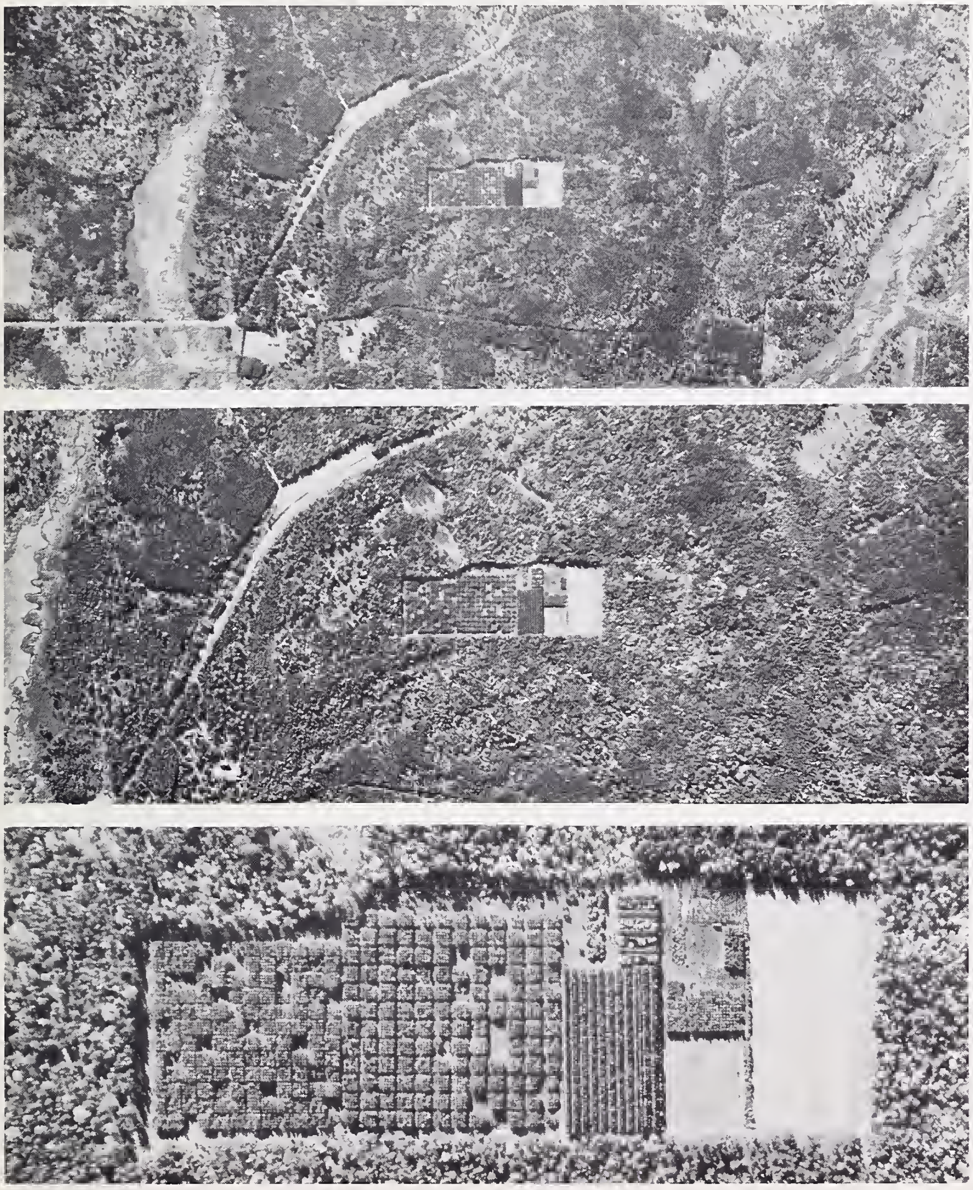

FIGURE 2. — Comparison of three different photographic scales of the same area in northern Minnesota. From top to bottom, prints were taken at scales of 1:24,000; 1:15,840; and 1:3,820 respectively. All are on panchromatic film. (Courtesy of Mark Hurd Aerial Surveys, Inc.)

work on the National Forests. Several agencies feel that 1:12,000 photos represent the best compromise between the opposing factors of cost and photographic detail. Both of these scales may be successfully used anywhere in the United States.

When photographic detail must be transferred to base maps, the number of prints that must be handled is quite often a critical factor in getting a job completed within reasonable time limits. Thus, in deciding which photographic scale should be used for a particular forest, it is valuable to know how many prints will be required to stereoscopically cover areas of different sizes. Table 2 supplies this information for five commonly used photographic scales.

Importance of Camera Focal Length

Roughly defined, the focal length is the distance from the camera lens to the photographic film held in the magazine.[2] It is a critical contract specification because it determines the altitude that must be maintained by the photographic aircraft to obtain negatives of the desired scale. Also, its direct effect on the image displacement of objects photographed controls the amount of third-dimensional exaggeration that the interpreter sees when viewing the finished prints stereoscopically.

Aerial cameras commonly used for forestry purposes have focal lengths of 6, 8-¼, or 12 inches (0.5, 0.6875, or 1.0 ft.). Knowledge of the focal length used, along with the altitude of the photographic aircraft, can be used to compute the natural scale of the exposed negatives:

$$\text{Scale or RF} = \frac{f}{H-h} = \frac{\text{Camera focal length (ft.)}}{\text{Altitude above ground datum (ft.)}}$$

Where: Scale is expressed as a representative fraction, and focal length and flight altitude are in the same units.

For example, with a camera focal length of 6 inches, a flight altitude of 8,000 above mean sea level (MSL), and an average ground elevation of 2,000 feet, the representative fraction would be computed as follows:

$$\text{RF} = \frac{0.5'}{8{,}000'-2{,}000'} = \frac{0.5}{6{,}000} = \frac{1}{12{,}000} \text{ or } 1{:}12{,}000$$

A more common application of this relationship might require the computation of the flight altitude that must be maintained to obtain a specified photo scale. Again assuming a camera focal length of 6 inches, a specified scale of 1:20,000 and an average ground elevation of 5,000 feet, the flight altitude above MSL would be calculated as follows:

$$\frac{1}{20{,}000} = \frac{0.5'}{H-5{,}000'};\ H - 5{,}000' = 10{,}000,$$

and H (altitude) = 15,000 feet above mean sea level.

It must be remembered that the photo scale as computed here is representative only of the datum, an imaginary plane passing through the specified ground elevation of 5,000 feet above sea level. Terrain features located *below* this elevation will appear at a smaller scale, and their images will also be displaced radially *inward* toward the photo center or nadir. All features located *above* the

TABLE 2. — *Approximate number of 9- by 9-inch prints required for stereoscopic coverage, by size of area and photo scale*[1]

Size of area (sq. miles)	Aerial photo scale				
	1:20,000 or 1,667 ft./in.	1:15,840 or 1,320 ft./in.	1:12,000 or 1,000 ft./in.	1:9,600 or 800 ft./in.	1:7,920 or 660 ft./in.
25	12	19	32	50	74
50	23	37	64	99	148
100	46	74	128	198	296
200	92	148	256	396	592
400	184	296	512	792	1,184
800	368	592	1,024	1,584	2,368
1,500	685	1,091	1,900	2,965	4,366
2,500	1,142	1,819	3,166	4,941	7,276
5,000	2,284	3,638	6,332	9,882	14,552

[1] *Assumes an average forward overlap of 60 percent and an average sidelap of 30 percent, or an effective area of about 22 square inches per print.*

[2] *See glossary of photogrammetric terms, p. 35.*

datum will be shown at a scale larger than 1:20,000, and their images will be displaced radially *outward* from the photo center.

Radial displacement of photographic images constitutes a source of error in measuring horizontal distances on aerial prints, but it is nevertheless

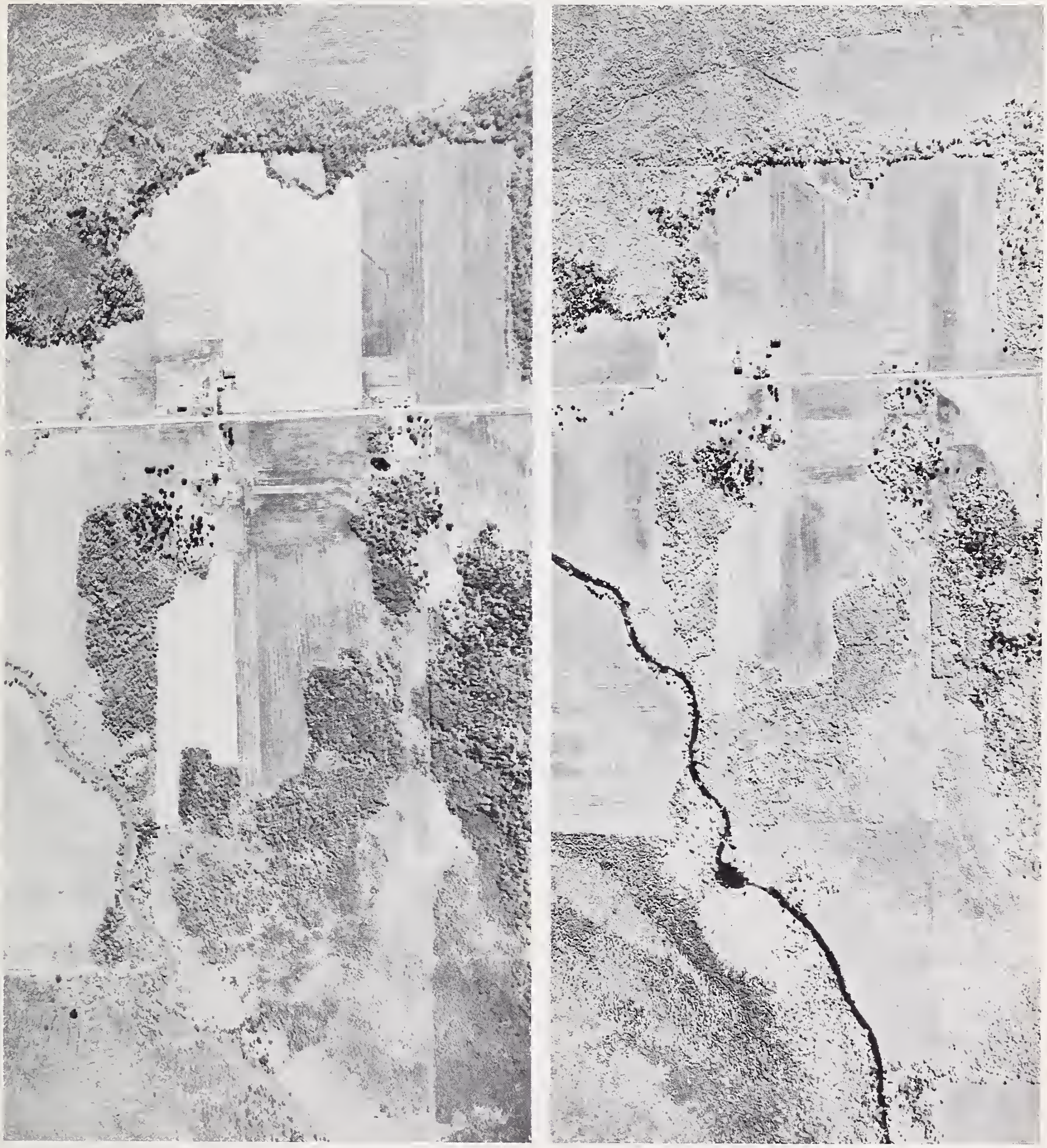

FIGURE 3. — Panchromatic (left) and infrared photography of an area in Chippewa County, Mich. The panchromatic exposure was made in late spring; the infrared in midsummer. Conifers may be separated from hardwoods on either print, although the contrast is more striking on infrared photography. As shown by the river in the left-hand corner of each print, water photographs black on infrared and grayish on panchromatic film. The panchromatic print is shown at a scale of about 800 feet per inch; the infrared photograph is reproduced at 1,000 feet per inch. (Courtesy of Abrams Aerial Survey Corporation.)

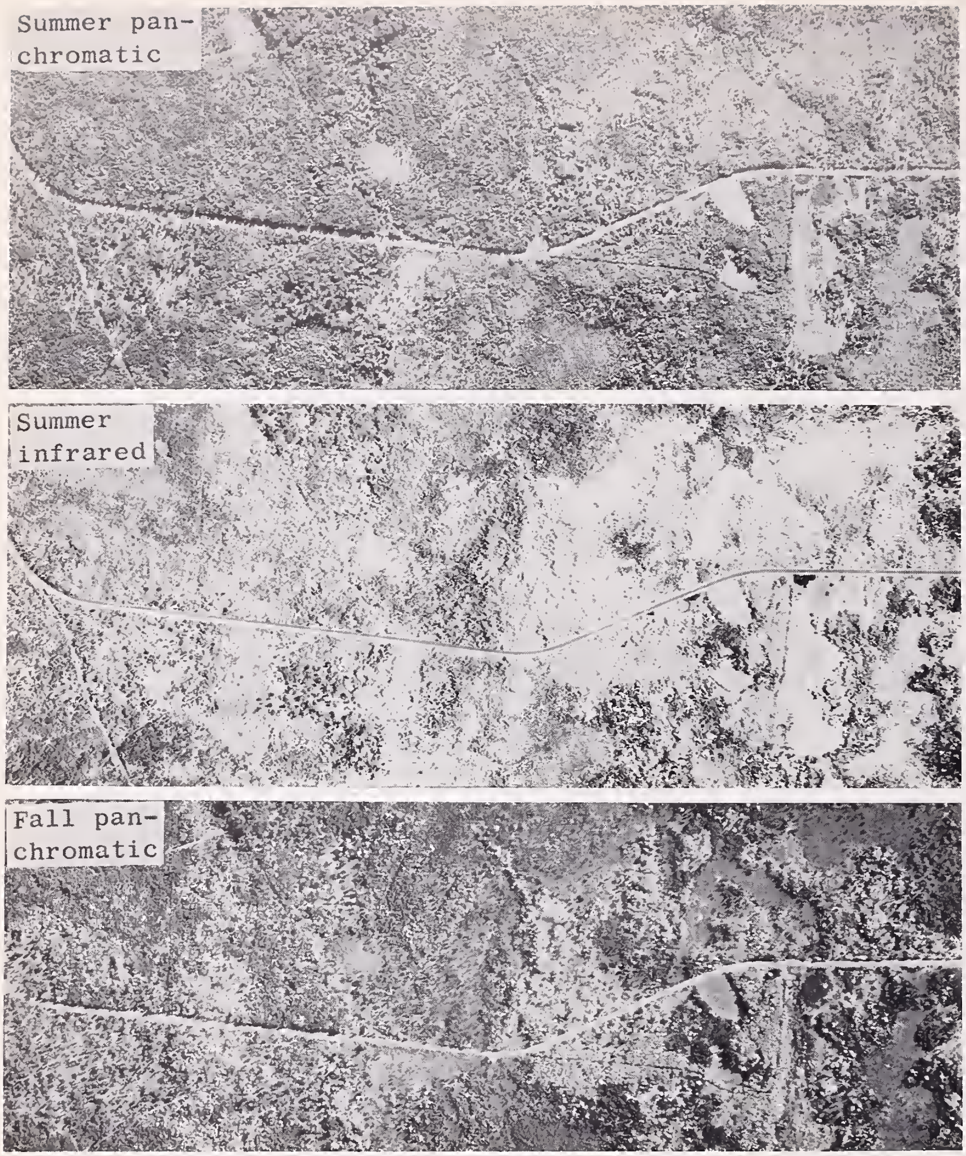

FIGURE 4. — Summer panchromatic and infrared photography compared with fall panchromatic prints of the same area in northern Minnesota. Note the light tonal rendition of hardwoods on the infrared and fall panchromatic as compared to summer panchromatic. Scale is 1:15,840. (Courtesy of Mark Hurd Aerial Surveys, Inc.)

the basis of three-dimensional photography. At a given scale, the use of shorter focal lengths results in a greater amount of photo-image displacement than longer ones. Thus, when it is desired to increase the exaggeration of the third dimension, as in relatively flat terrain, a focal length of 6 inches may be specified. Conversely, in extremely mountainous country, a longer focal length might be required because an excessive degree of image displacement makes stereoscopic viewing of the prints difficult.

The 8¼-inch camera focal length supposedly represents a compromise between 6 and 12 inches, but few of the newer aerial cameras with modern lens systems employ this focal length. A 6-inch, distortion-free lens can be used with much better results than older cameras having 8¼-inch focal lengths, and is therefore recommended where local relief is not excessive (*10*). In rougher terrain, cameras with 12-inch or longer focal lengths may be required.

Panchromatic Versus Infrared Film

Foresters usually prefer aerial photographs that will enable them to differentiate readily between tree species or forest types. As a minimum, softwoods, hardwoods, and mixtures of the two groups must be separable. This is not always a simple requirement to satisfy, for photographic films are not particularly sensitive to the green light waves reflected from healthy plant foliage.

Only two basic kinds of black-and-white film, *Panchromatic* and *infrared,* are ordinarily available for aerial photography in the United States. Though panchromatic is more easily obtained and enjoys wider usage, both types may be successfully employed for photographing green vegetation when exposure conditions are favorable (2, pp. 19-98).

Any black-and-white photographs taken in winter will show sharp tonal contrasts between deciduous and evergreen species, but trees lacking foliage cannot be adequately assessed for timber inventory purposes. Growing-season photography is thus preferred wherever hardwoods constitute an economically important component of the forest stand structure.

Panchromatic photography taken during the *middle* of the growing season, i.e., when foliage is fully developed and pigmented, usually depicts all tree crowns in a uniformly grayish tone (fig. 3). The lack of contrast between various species groups makes reliable forest-type identifications difficult in some regions — virtually impossible in others. Although this may not be a serious handicap in western regions where conifers predominate, it severely reduces the interpretation value of photographs in eastern or southern mixed forests (*5*). As a partial solution to the problem, photographic flights can be limited to spring or fall seasons when there are striking tonal contrasts in foliage coloration between various tree species.

In the Lake States, for example, it has been found that panchromatic film provides good results in late fall — just before deciduous species such as aspen or tamarack shed their leaves. For a brief period of perhaps 2 weeks' duration, foliage color differences will result in good photographic contrasts between most of the important forest types (fig. 4). It seems likely that this time schedule might produce equally satisfactory prints in the northeast, where species associations are similar to those in the Lake States.

Spring panchromatic photography, taken when deciduous foliage is partially developed, has been used to a limited extent in the Lake States and has resulted in excellent conifer-hardwood differentiation (fig. 5). It requires careful planning and timing, however, since the period is short and often subject to cloudy weather. In addition, not all deciduous species produce leaves simultaneously, and commencement of photography must be based upon ground inspection of the vegetation.

Correctly exposed infrared photography of mixed hardwood and coniferous forests displays sharp tonal contrast between the two groups. Broadleaved (hardwood) species photograph in a whitish-gray tone, while the crowns of needle-bearing trees (softwoods) appear much darker (figs. 3, 4). Although black shadows tend to obscure ground detail to some extent, infrared photography should be given prime consideration in southern and southeastern regions where mixed forests cover large areas (*5*). Recent infrared photography of the Ouachita (Arkansas), Chippewa (Minnesota), and Huron (Michigan) National Forests indicates its utility under diverse forest conditions.

Both panchromatic and infrared photographs are ordinarily taken with yellow haze filters. These are often referred to as "minus-blue" filters, because their primary function is to reduce the amount of blue light (haze) that passes through the lens to the film. To obtain infrared photography with the greatest possible degree of contrast, red or green filters can be used instead, but "modified infrared" photography produced with a minus-blue filter has generally been found most satisfactory.

Season of Photography

From the foregoing it is apparent that the best time of year for scheduling photographic flights is dependent on the film to be used, the tree species-groups that must be recognized, and the number of days suitable for aerial photography within a given period of time. Unfortunately, the greatest number of clear, sunny days may not always coincide with the season when photography is desired. Table 3 was prepared from U. S. Weather Bureau records to illustrate the average number of "photographic days" per month within each State.

If photography is planned during the dormant season when deciduous trees are leafless, panchromatic film should always be specified. There would be little advantage in using infrared film under such conditions, for shadows are more offensive and costs may be greater. When panchromatic film is to be used during the growing season, an effort should be made to plan photographic flights in early spring or late fall to take advantage of maximum differences in foliage coloration.

As for infrared film, experience has shown that merely limiting its use to the growing season does not always produce the desired results. Here again, the early period of leaf development appears to be the best time for photography. In southern

TABLE 3. — *Average number of days suitable for aerial photography, by State and month of year*[1]

Name of State[2]	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total per year
Alabama	6.4	6.4	6.9	6.5	6.2	4.1	2.4	2.9	5.9	11.4	9.7	6.3	75.1
Arizona	15.3	13.2	15.7	18.3	22.0	23.7	15.8	15.8	20.2	21.5	18.3	16.2	216.0
Arkansas	7.0	6.9	6.6	6.5	5.6	5.8	5.7	7.2	9.1	11.8	9.0	7.8	89.0
California	7.4	6.7	8.4	9.3	9.7	11.5	12.7	12.8	13.3	13.1	10.8	8.6	124.3
Colorado	7.5	5.8	5.7	4.6	4.6	7.0	5.5	5.4	10.3	11.3	9.4	8.4	85.5
Connecticut	6.1	7.1	7.6	6.4	6.8	5.2	5.4	6.4	6.7	9.1	6.1	6.6	79.5
Delaware	5.5	5.7	5.6	5.2	5.5	4.0	4.5	4.7	6.6	9.2	6.4	5.5	68.4
Florida	5.9	6.7	7.4	6.7	5.0	2.7	1.4	1.5	2.8	6.0	7.7	6.3	60.1
Georgia	6.8	7.1	7.9	7.3	6.6	4.1	2.4	3.0	5.6	10.8	10.6	7.3	79.5
Idaho	2.7	3.7	4.3	4.6	5.5	8.8	13.3	18.4	12.5	9.8	5.7	3.5	92.8
Illinois	4.9	4.7	4.8	5.1	5.1	4.5	6.3	6.5	7.9	9.0	6.4	5.1	70.3
Indiana	4.2	3.8	4.2	4.5	4.4	3.7	4.9	5.4	7.1	9.2	6.2	4.4	62.0
Iowa	5.8	5.4	4.8	5.3	5.0	4.8	7.2	6.6	7.8	8.9	5.9	5.4	72.9
Kansas	8.5	7.3	6.7	5.8	5.6	6.2	8.7	8.2	9.6	10.7	9.6	8.4	95.3
Kentucky	4.8	4.8	5.2	5.4	6.1	5.8	7.2	6.3	8.4	10.7	7.2	4.9	76.8
Louisiana	6.9	6.3	6.6	6.9	6.2	5.7	3.9	4.7	7.3	11.3	9.6	6.8	82.2
Maine	5.6	6.3	5.8	4.8	3.8	3.4	3.4	4.6	5.8	6.8	4.0	5.3	59.6
Maryland	5.2	5.5	5.4	5.0	5.0	3.8	4.1	4.3	6.3	8.9	6.0	5.4	64.9
Massachusetts	3.6	4.2	4.5	4.0	3.5	2.5	2.2	3.6	4.2	5.1	3.5	3.4	44.3
Michigan	2.2	3.1	4.1	5.0	4.8	4.6	5.4	4.6	4.6	4.3	1.9	1.9	46.5
Minnesota	5.4	5.8	5.2	5.8	5.6	4.9	7.1	6.8	6.2	6.3	4.2	5.1	68.4
Mississippi	6.3	5.8	6.8	6.3	5.7	5.5	3.2	3.8	6.6	11.8	9.4	6.2	77.4
Missouri	7.4	7.1	6.8	6.8	6.8	6.8	9.2	8.9	9.9	11.6	9.2	7.3	97.8
Montana	3.5	3.7	3.5	4.1	3.8	4.2	9.9	9.0	7.3	6.9	4.3	4.0	64.2
Nebraska	6.9	5.7	5.3	4.9	4.7	5.5	8.4	7.4	8.9	10.2	7.1	6.9	81.9
Nevada	6.7	6.2	7.5	8.4	8.7	13.8	18.6	18.8	16.9	14.2	10.1	7.4	137.3
New Hampshire	3.3	3.8	4.1	3.7	3.2	2.2	2.0	3.0	3.8	4.4	2.8	2.9	39.2
New Jersey	6.1	6.2	6.1	5.6	6.5	4.5	5.3	5.6	7.1	9.9	7.3	5.9	76.1
New Mexico	10.5	8.4	8.7	8.3	8.1	10.5	5.4	5.3	10.2	14.0	12.7	12.3	114.4
New York	2.3	2.9	4.1	4.9	5.5	4.8	4.8	4.7	5.5	5.1	2.5	2.0	49.1
North Carolina	6.8	6.8	7.3	7.1	6.7	4.2	3.6	3.9	6.1	11.1	10.1	7.4	81.1
North Dakota	5.0	4.9	4.4	5.3	5.1	4.3	7.5	7.2	6.7	6.6	4.3	5.3	66.6
Ohio	3.5	3.1	4.1	4.8	5.8	5.1	6.2	6.2	7.3	7.1	4.3	2.9	60.4
Oklahoma	8.0	6.7	6.5	5.8	5.4	6.7	7.6	8.7	9.5	10.8	10.3	8.3	94.3
Oregon	2.0	2.6	3.0	4.7	5.0	6.8	13.4	13.2	9.5	6.2	2.9	2.1	71.4
Pennsylvania	3.0	3.2	3.9	4.2	4.9	3.7	3.9	4.2	5.8	6.4	3.4	2.5	49.1
Rhode Island	4.9	5.3	6.6	5.8	5.9	4.0	5.1	6.1	6.6	7.8	5.3	4.4	67.8
South Carolina	6.4	7.0	7.1	7.0	6.0	3.3	2.3	2.9	5.0	10.1	10.3	7.2	74.6
South Dakota	5.9	5.4	4.9	4.8	4.5	5.0	8.2	8.3	8.6	8.9	6.4	6.7	77.6
Tennessee	5.3	5.5	6.2	5.4	5.7	4.5	4.2	5.1	7.1	11.2	8.8	5.9	74.9
Texas	7.8	6.3	7.2	7.1	6.4	7.4	5.7	6.7	7.6	11.1	8.9	7.9	90.1
Utah	7.1	5.8	7.0	7.1	7.8	12.6	11.0	11.3	14.2	13.7	10.4	7.6	115.6
Vermont	2.9	2.9	3.3	3.1	2.7	1.7	1.6	2.0	3.2	3.2	1.5	1.8	29.9
Virginia	5.4	5.6	5.6	6.1	5.9	4.1	4.3	4.4	6.0	9.2	7.1	5.6	69.3
Washington	1.3	2.1	2.6	3.7	3.8	5.1	11.6	11.1	7.5	4.9	1.6	1.2	56.5
West Virginia	2.3	2.2	3.6	3.8	4.2	3.0	3.2	3.0	4.0	4.7	3.2	2.0	39.2
Wisconsin	4.9	5.3	4.6	5.1	5.4	4.6	7.0	6.5	6.4	7.2	4.4	4.7	66.1
Wyoming	4.7	4.5	4.3	3.8	3.2	4.8	6.9	6.7	8.2	7.9	5.7	5.5	66.2

[1] *Compiled from U. S. Weather Bureau Records. Figures shown represent the number of days per month with 10 percent cloud cover or less. Averages should be used with discretion, as wide variations may occur from one part of a state to another.*

[2] *Data unavailable for Alaska and Hawaii.*

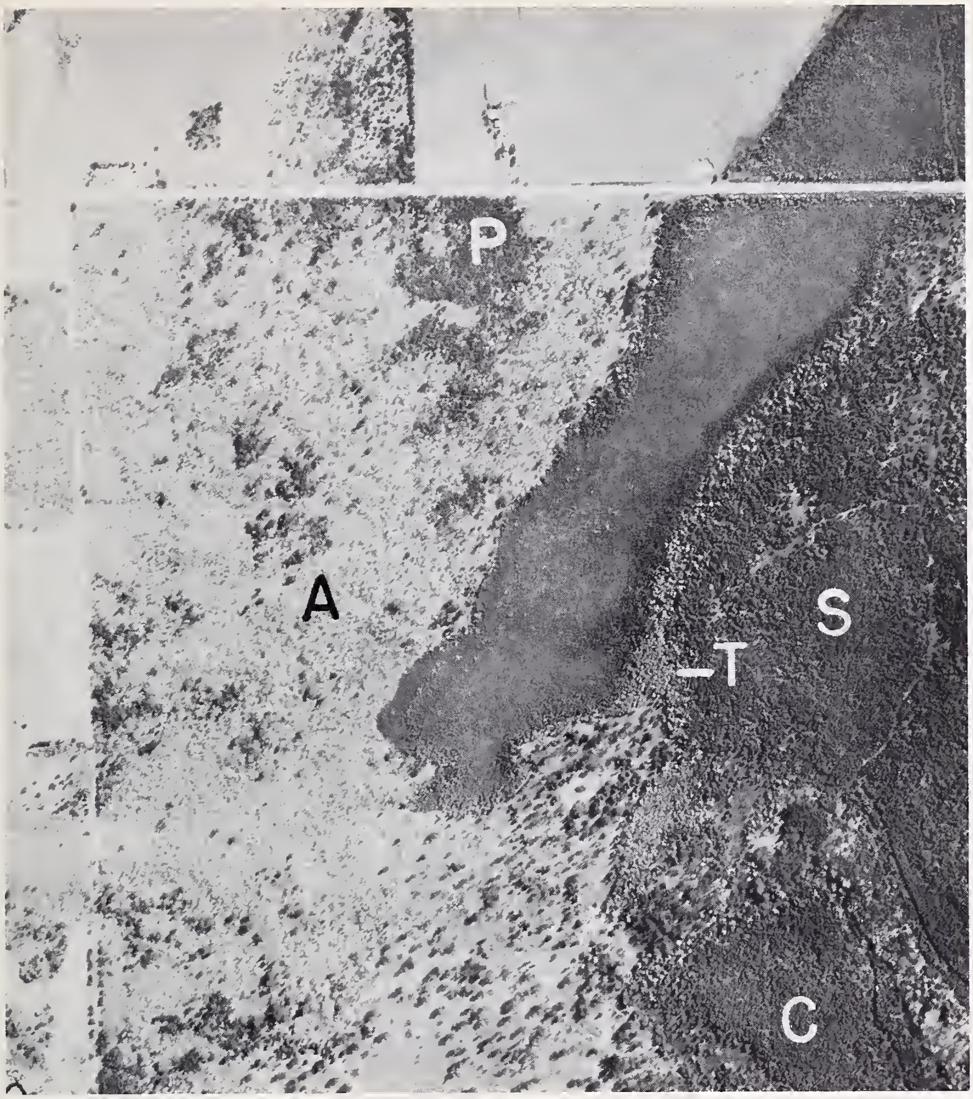

FIGURE 5. — Spring panchromatic photography of an area in northern Minnesota, taken in May at a scale of 1:8,800. Note the contrast between such light-toned species as aspen-birch (A) and tamarack (T) and the darker tones of jack pine (P), black spruce (S), and cedar (C).

United States, superior infrared exposures are obtained in late spring or early summer — after all trees have produce some foliage, but prior to maximum pigmentation. If large expenditures are anticipated for infrared photography, the purchaser would be wise to request print samples from several aerial survey companies. It is a matter of record that infrared film has lost favor in some forest regions because of insufficient knowledge of its exposure characteristics under varying season conditions. Experience in the Lake States has shown that infrared photography after fall coloration of deciduous trees has commenced is considerably less desirable than that obtained at the height of summer foliage condition. As a matter of fact, the conifer-hardwood differentiation has, in some cases, been found to begin deterioration several weeks before fall coloration becomes apparent to the eye. Plans for infrared photography at the close of summer in this area should, therefore, be approached with considerable caution.

Of seasonal significance is a phenomenon known as "hotspot" (fig. 6). This takes place when a straight line from the sun through the aircraft intersects the ground inside the area of photo coverage. At the very center of the hotspot is a point of "no-shadow" due to the direct return of the light rays to the lens with subsequent overexposure and loss of detail. This effect decreases progressively away from the no-shadow point and, in general, will not materially reduce image quality in an area of

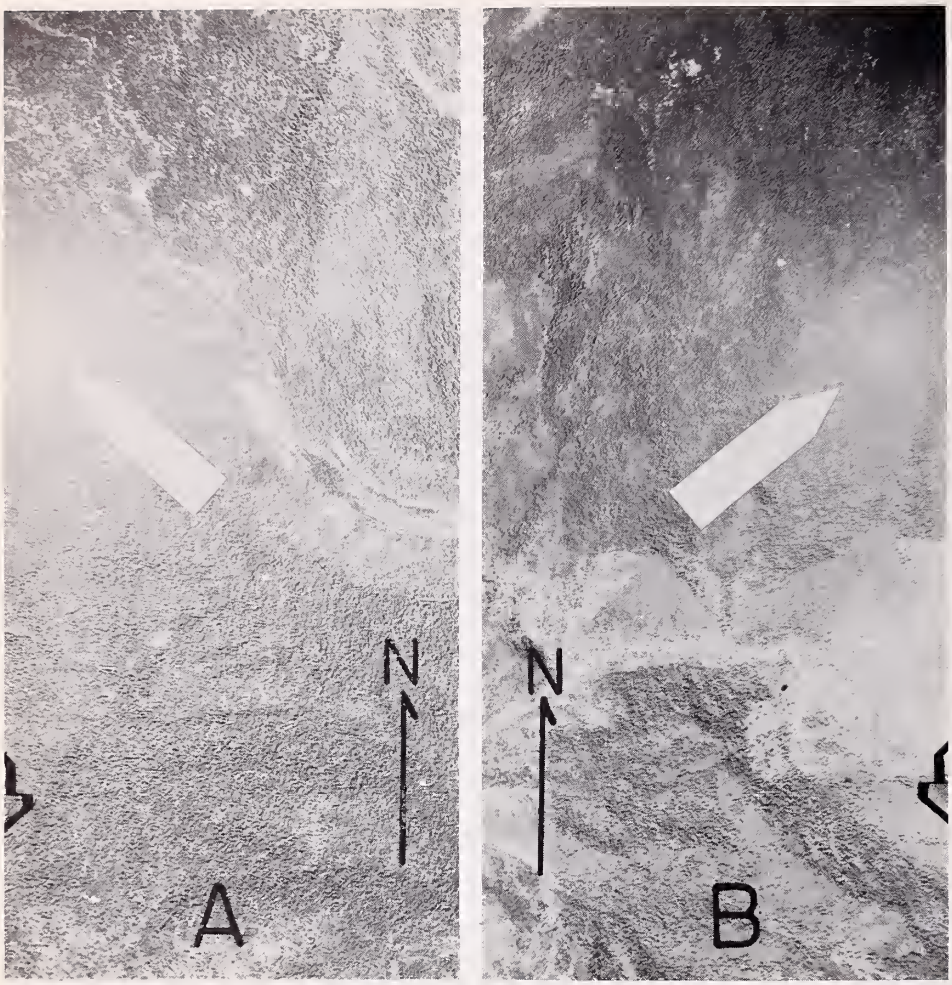

FIGURE 6. Portions of two photographs from a Pacific Northwest area flown in July and August. Photo A, of which the northwest portion (less titling) is shown, was exposed at approximately 10:30 A.M. Photo B, of which the northeast portion (less titling) is shown, was exposed at approximately 2:30 P.M. Observe how the hotspot has traveled from the northwest edge of the forenoon photography to the northeast edge of the midafternoon photography.

more than about an inch in diameter on the negative. Detail will sometimes be lost over a greater area but skillful dodging during printing will usually reduce serious image loss to a spot under one inch in diameter.

The sun angle is highest in the spring and early summer and hotspot is most likely to occur at that time. Also its chance of occurrence increases as the angle of coverage of the lens increases. Its location at various times of day and season can be calculated (*7*). Although hotspots result in some detail loss, at least one major mapping agency considers this less serious than the loss of time involved in avoiding them (*6*).

Summing up the Cost Factors

The actual cost of contract aerial photography will obviously change with time, locale, and fluctuations in the business activities of aerial survey companies. As any quotation must be limited to a set of fixed conditions, it is not surprising that there have been few published accounts of contract photography prices. A recent report dealt with the combined cost of aerial photography and topographic mapping (*11*), but such figures are not applicable where only contact prints and photo indexes are desired.

The two factors normally having the greatest influence on photographic costs are scale and size of area involved. Stated simply, prices per square mile increase as the scale becomes larger and as the area covered becomes smaller. This relationship is immediately evident from the listing of photographic costs in table 4. The influence of photo scale in terms of number of prints required may be evaluated by comparing table 4 with table 2. The actual prices shown are not intended to serve any one region of the United States, but the use of ratios between values should provide a valid index for making rough cost estimates.

The relatively high cost per square mile associated with small areas is worthy of explanation. First of all, the cost of moving a photographic crew and aircraft 200 to 300 miles is likely to exceed $1,000. Secondly, inclement weather may impose an extended period of idle waiting for a photographic flight that could be accomplished in less than one day. For coverage at 1:15,840 (4 inches per mile), a good camera crew can photograph 750 to 900 square miles in 5 to 8 hours of flying time. Hence, photo coverage of small tracts will be influenced more by the cost of moving plane and crew than by the actual flying time that may be involved.

At the opposite end of the cost yardstick, federal agencies such as the Commodity Stabilization Service may obtain photographic coverage for as low as $2 to $4 per square mile. These lower prices are obtained because photo scales are relatively small (1:15,840 to 1:20,000) and area covered may range from 2,500 to more than 10,000 square miles for a single project. In addition, certain specifications (such as season, time of photography, or condition of vegetation) may be less stringent than in other contracts.

As previously outlined, photographic costs may vary considerably by season of year, because of weather conditions or fluctuating demands for services of aerial survey firms. Companies whose activities are heavily oriented toward topographic mapping are likely to have their photographic work concentrated during the season when terrain features are most clearly visible, i.e., when deciduous trees are bare and when the ground is free of snow cover. Thus the "slack season" for many businesses may roughly coincide with the vegetational growing season — an advantageous situation from the forester's standpoint.

In areas such as Alaska, heavy winter snows combine with a persistent summer cloud cover to practically eliminate good photographic conditions. The risks inherent in obtaining coverage of such areas are likely to be reflected in prices that are double or triple those shown in table 4.

Though it is not generally a serious deterrent, the cost of obtaining infrared photography at a given scale may be 5 to 25 percent greater than for panchromatic coverage. This is due to the fact that infrared film is manufactured only on special order, and most aerial survey firms do not carry it in stock. Also, aerial cameras that have been calibrated and tested for exposure of panchromatic film must undergo slight alterations in focal length to assure sharp infrared negatives. This is an added expenditure to the company as altered cameras must be sent to the Bureau of Standards in Washington, D. C., for re-inspection and approval. While these "behind-the-scenes" activities are not of direct concern to the purchaser, they can nevertheless delay photographic coverage. Therefore, advance planning is of utmost importance when infrared photography is contemplated.

TABLE 4. — *Approximate cost per square mile for contract aerial photography, by size of area and photo scale*[1]

Size of area (sq. miles)	Aerial photo scale				
	1:20,000 or 1,667 ft./in.	1:15,840 or 1,320 ft./in.	1:12,000 or 1,000 ft./in.	1:9,600 or 800 ft./in.	1:7,920 or 660 ft./in.
25	$35.00	$40.00	$42.00	$45.00	$50.00
50	20.00	22.00	26.00	30.00	45.00
100	12.50	15.00	20.00	25.00	35.00
200	8.60	13.80	18.00	20.00	27.00
400	7.50	12.00	15.00	17.00	23.00
800	6.20	9.90	12.00	14.00	18.00
1,500	5.10	8.20	10.00	12.00	17.00
2,500	4.80	7.70	9.00	11.00	16.00
5,000	4.20	6.70	8.00	10.00	15.00

[1] *Prices listed represent averages from several sources, and thus do not apply to any specific area. In all instances, stereoscopic coverage on black-and-white (panchromatic) film is assumed. Cost of ground control work and preparation of maps from the photographs are NOT included.*

FLIGHT PLANNING

An aerial flight plan is simply a reliable map depicting the area to be photographed, scale of photography desired, and proposed location of flight lines (fig. 7). Even though the final version may be prepared by the contractor, it is usually to the purchaser's advantage to draw up a preliminary plan prior to issuing bid invitations.

Base maps suitable for flight planning may be obtained at a nominal cost from several public agencies. An index to maps currently available from the federal government may be obtained by writing to: Map Information Office, U. S. Department of the Interior, Geological Survey, Washington 25, D. C.

Topographic quadrangle sheets, ranging in scale from 1:24,000 to 1:250,000, are among the best maps readily available for preparing flight plans. The example that follows illustrates the various calculations involved in preparing an aerial flight plan for an area of 80 square miles:

Basic Information

Scale of base map: 1:62,500 or 1 inch = 5,208 feet.

Size of area: 8 miles E-W by 10 miles N-S, or 42,240 feet by 52,800 feet.

Average ground elevation above mean sea level: 1,200 feet.

Photo scale desired: 1:15,840 or 1,320 feet per inch.

Average forward overlap: 60 percent.

Sidelap: 15 to 45 percent, averaging approximately 30 percent.

Negative format: 9 by 9 inches or 11,880 feet by 11,880 feet on the ground.

Camera focal length: 6 inches or 0.5 foot.

Items To Be Computed

1. Flying height above ground and height above mean sea level.
2. Direction and number of flight lines.
3. Ground distance between flight lines.
4. Actual percent of sidelap.
5. Map distance between flight lines.
6. Ground distance between exposures on each line.
7. Map distance between exposures on each line.
8. Number of exposures on each line and total number of exposures.

Calculations

1. Flying height above ground datum: Height = focal length X scale denominator.

H = 0.5′ X 15,840 = 7,920 feet above ground.

Flying height above mean sea level: 7,920 + 1,200 = 9,120 feet.

2. Direction of flight lines: North-South, following long dimension of tract.
   Number of flight lines: Assuming an average sidelap of 30 percent, the lateral gain from one line to another is 70 percent of the print width, or 0.70 X 11,880 = 8,316 feet between lines. The number of *intervals* between lines is found by dividing the tract width (42,240 feet) by 8,316. The result is 5.08 or *5 intervals* and *6 flight lines.*

3. Ground distance between flight lines:

   Tract width (42,240) ÷ 5 intervals = 8,448 feet between lines.

4. Actual percent of sidelap:

$$\text{Sidelap Percent} = \frac{\text{Print width (ft.) - Spacing (ft.)}}{\text{Print width (ft.)}} \times 100$$

$$\text{Sidelap Percent} = \frac{11{,}880 - 8{,}448}{11{,}880} \times 100 = 28.9 \text{ percent}$$

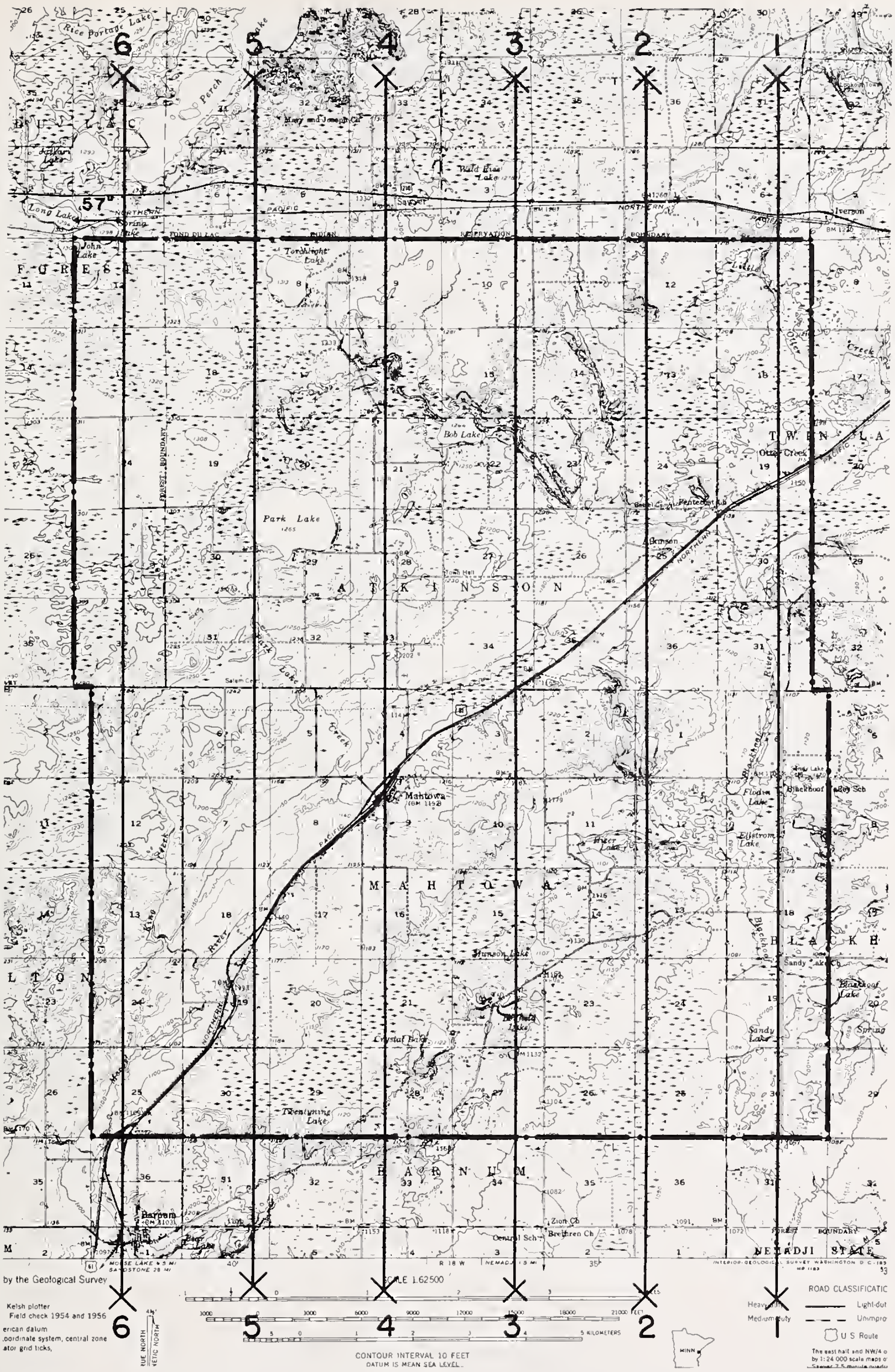

FIGURE 7. — A sample flight plan for aerial photography (shown at reduced scale). Tract boundaries and flight lines have been marked for use by pilot and aerial photographer.

5. Map distance between flight lines: (Map scale: 1″ = 5,208 feet)

$$\frac{1''}{5{,}208'} = \frac{X''}{8{,}448'};\ X = 1.62''\text{ between lines on map.}$$

6. Ground distance between exposures on each line: Assuming an average forward overlap of 60 percent, the spacing between successive exposures is 40 percent of the print width, or 0.40 X 11,880 = 4,752 feet.

7. Map distance between exposures on each line:

$$\frac{1''}{5{,}208'} = \frac{X''}{4{,}752'};\ X = 0.91''\text{ between exposures on map.}$$

8. Number of exposures on each line: Number of *intervals* between exposures is found by dividing tract length (52,800 feet) by 4,752 = 11.11 *intervals*. This would require 12 exposures *inside* the area, assuming that the first exposure is centered over one tract boundary. In addition, two extra exposures are commonly made at the ends of each line; thus, a total of 12 ÷ 2 + 2 = 16 *exposures* would be taken on each flight line.

Total number of exposures required to cover entire tract: 6 lines X 16 exposures per line = 96 exposures.

SELECTING AN AERIAL SURVEY FIRM

In the preceding pages, emphasis has been placed on the various factors that directly affect the cost of aerial photography. This was done so that prospective purchasers might make more intelligent choices among the alternatives of photo scales, films, and seasons available. It should not be inferred, however, that cost is the sole consideration; in many instances, its final significance may be secondary.

The prime objective, of course, is to obtain high-quality photographs from which interpreters can readily extract information desired. Low-priced aerial photographs that do not satisfactorily meet this standard cannot be considered inexpensive by any measure. In short, bargain rates for aerial photography are rarely correlated with careful planning and precise photogrammetric methods. In everyday consumer terms, the cheapest price is not necessarily synonymous with the "best buy." Although the next section of this bulletin deals specificially with bid invitations, it is noteworthy that many photographic contracts are now handled by direct negotiation on a professional level between the parties involved. This is a healthy trend, for it can protect both the buyer and the reliable aerial surveyor from unscrupulous operators.

The simple solution to the problem is to negotiate only with reputable aerial survey firms that maintain high standards of excellence in their work. Many such companies are found throughout the United States and Canada. While it would be inappropriate to list all of them here, the reader may obtain names and addresses from the Association of Professional Photogrammetrists[3] or from any current issue of *Photogrammetric Engineering,* the official technical journal of the American Society of Photogrammetry.[4] The Annual Yearbook issue, usually published in April, contains detailed reports of recent photogrammetric activities by many of these companies.

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[3] *The Benson-East, 100 York Road, Jenkintown, Pa.*

[4] *Further information may be obtained through Society headquarters at 1515 Massachusetts Avenue N. W., Washington 5, D. C.*

ISSUING BID INVITATIONS

Once the prospective purchaser of aerial photography has decided upon basic specifications and a flight plan, he is ready to issue bid invitations for the project. Such invitations may be mailed directly to selected aerial survey companies or advertised in newspapers and periodicals.

Copies of the flight plan and contract specifications commonly accompany the advertisement. Both invitations and photographic contracts assume a variety of forms, and those presented here are merely indicative of the principal items included in such documents. For additional information the reader should refer to standard specifications issued by government agencies.[5] Copies are normally available upon request.

INVITATION TO BID AND PROJECT DESCRIPTION[6]

1. Company issuing bid
(name and mailing address)

2. Date issued ________________________

3. Closing date ________________________

4. *Objective of advertisement*

To obtain aerial photography for an area of ________ square miles, located in ____________ County, State of ______________, in accordance with the following schedule and contract specifications. The company (purchaser) issuing this notice reserves the right to reject any or all bids submitted.

5. *Area, scale, and line direction*

All areas shown on the accompanying flight plan (see fig. 7) are to be stereoscopically covered by aerial photographs at a scale of __________ Flight lines will be run in a (north-south) (east-west) direction.

6. *Film, filter, and season*

Photography is desired on (panchromatic) (infrared) film; all exposures will be made with a (minus-blue) __________ (other) filter. Flights will be limited to a period defined by the purchaser during the month(s) of __________ when tree foliage conditions are satisfactory for photography.

7. *Aerial camera and focal length*

The aerial camera employed for this photography must meet all requirements in the contract specifications. A camera focal length of (6.0) (8.25) (12.0) ______ inches will be required for this project.

8. *Materials to be delivered*

Two sets of contact prints on (glossy) (semimatte). ________ weight paper and two sets of photo index sheets will be required, along with a copy of the original flight log showing photographic times and dates for each flight line. All materials must be ready for final inspection and delivery within ______ days following completion of flight operations.

9. *Bid requirements*

No bids will be given consideration unless accompanied by the following:

a. Two sample negatives and contact prints taken with the camera to be used for this project. Prints must be made without mask on ____ weight paper having a (glossy) (semi-matte) finish. The trade name of the photo paper and the contrast grade should be indicated for all prints submitted.

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[5] *Unpublished papers by: U. S. Department of Agriculture. Standard specifications for aerial photography, Spec. A-AP-1101, 25 pp. (mimeo.), 1939. Specifications for a precision airplane mapping camera, Spec. A-APC-1102, 4 pp. (mimeo.), 1940. Forest Service supplement to specifications A-AP-1101 and A-APC-1102, 12 pp. (mimeo.), 1952. U. S. Department of the Interior. Standard specifications for aerial photography for stereoplotting instruments, 24 pp. (mimeo.), 1960.*

[6] *U. S. Government agencies issue Standard Form 33, Invitation, Bid, and Award, in lieu of the form shown here.*

b. A National Bureau of Standards certificate for the aerial camera to be used, plus a notarized report covering any camera alterations that have been made since the most recent inspection and calibration.

c. A certified financial statement of the bidder's assets and liabilities.

d. A guarantee amounting to at least 10 per cent of the bid submitted, except that this requirement will be waived when the bid total is less than $1,000. All such guarantees will be returned to unsuccessful bidders within ____ days following the award of the contract. The guarantee deposited by the successful bidder will be returned upon receipt of his performance bond as described in the contract.

10. *Bidder's statement*

The photographic project described above will be undertaken at a rate of $______ per square mile, or a total price of $__________

(Name and address of
company submitting bid)

____
(Signature and title
of person signing bid)

A SAMPLE CONTRACT FOR AERIAL PHOTOGRAPHY

SECTION I — BUSINESS ARRANGEMENTS [7]

1. *Performance bond*

A formal contract and performance bond will not be required where the bid award is $2,000 or less. In all other cases, the bidder will enter into a formal contract and post a performance bond amounting to 50 percent of the contract price.[8]

2. *Award and notice to proceed*

Where the contract award does not exceed $2,000, the notice of award will authorize the successful bidder to commence operations as soon as tree foliage conditions are satisfactory for photography. If the contract award exceeds $2,000, the notice to proceed will be issued only after receipt of the performance bond.

3. *Commencement of flight operations*

At the time of the award, the purchaser will supply the successful bidder (contractor) with three copies of flight maps for the project. Upon receipt of the award notice, the contractor shall notify the purchaser where flying operations will be based for the project. Weather permitting, photographic flights must be started within 5 calendar days after receipt of the notice to proceed. Unless otherwise authorized in writing, the contractor must maintain a continuous standby of equipment and personnel until the project has been completed.

4. *Progress reports*

Immediately following each 7-day period of operations, a progress report shall be furnished to the purchaser. Such reports should indicate, for each day, the number of hours flown, times of day when photography was started and terminated, number of flight lines and exposures taken, prevailing weather conditions, and a cumulative summary of work completed to date.

5. *Periodic inspections and reflights*

Upon commencement of flight operations, the contractor shall notify the purchaser of the film-processing location. Provision shall be made for the purchaser's representative to inspect negatives and prints as the work progresses, so that any required reflights can be scheduled from the some base of operations. Where the entire photographic project is completed in one week or less, it may be most efficient to inspect all negatives and prints at one time. If reflights are required, however, the purchaser will not be liable for added costs occasioned by the premature relocation of photographic plane and crew by the contractor. The critical seasonal requirements of forest resource photography make it mandatory that reflights be scheduled within 10 photographic days following notification to the contractor.

6. *Risks and damages*

The contractor agrees to assume all risks involved in the completion of the photographic project and assumes full responsibility for the safety and liability of his personnel and equipment. Unless so authorized in writing by the purchaser, the contractor shall not subcontract any portion of the work covered by this agreement.

7. *Delays and cancellation*

If the contractor fails to undertake the project as set forth in the notice to proceed, or if flight operations are suspended without adequate explanation when seasonal and weather conditions are suitable for photography, he may be liable for a damage assessment. Such damages will be withheld from the performance bond deposited with the purchaser. If normal operations are not resumed within 5 photographic days following written notification to the contractor, the purchaser shall have the privilege of cancelling the contract and collecting damages at the prescribed rate.

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[7] *In the following sections dealing with photo specifications, the organization requesting aerial photography is referred to as the* purchaser; *the aerial survey firm undertaking the photographic operation is designated as the* contractor.

[8] *Values herein prescribed for performance bonds, payments, penalties, and time limitations are* suggested only *and are likely to vary from one contract to another.*

8. *Final inspection and delivery*

When all photography and reflights have been completed, the contractor shall arrange to have materials ready for final inspection within 30 calendar days. Following inspection and acceptance, the required number of prints and photo indexes shall be delivered to the purchaser within an additional 21 days. All photographic materials shall be shipped *prepaid* and *insured* against loss or damage in transit. Original shipping memoranda shall be forwarded to the purchaser via air mail.

9. *Payment to contractor*

If the contract price is $1,000 or less, payment-in-full will be made by the purchaser immediately upon formal acceptance and receipt of photographic materials. Where the contract price exceeds $1,000, partial payments may be made (at the purchaser's discretion) as work progresses. In such cases, final payment will be withheld until acceptance and delivery of materials.

10. *Ownership of negatives*

Photographic negatives will be stored by the contractor, but remain the exclusive property of the purchaser. No duplicate prints from these negatives may be sold without written authorization from the purchaser.

SECTION II — THE PHOTOGRAPHIC SURVEY[9]

1. *Areas to be photographed*

Location, dimensions, and boundaries of the area to be photographed are specified in the bid invitation and drawn on the three accompanying flight maps. It is explicitly agreed that such dimensions are approximate only.

2. *Plane and camera crew*

The photographic aircraft must be capable of sustained efficient performance at the altitude required for this photography. Both pilot and aerial photographer must be fully qualified and competent to obtain photography conforming to all requirements specified. The purchaser shall have the right to reject any changes in the camera crew when there is evidence that proposed substitutes are unable to perform their work satisfactorily.

3. *Photographic scale*

All negatives shall be exposed at the proper altitude(s) above mean sea level to yield contact prints at the specified scale. After allowance for topography, the average scale for each flight line should show a variation of not more than plus or minus 5 percent. Larger scale departures may result in the rejection of an entire flight line.

4. *Flight line positioning and orientation*

The center of each flight line shall coincide as closely as possible with the position plotted on accompanying flight maps. No strip shall depart from its plotted location by more than 25 percent of the mean sidelap distance. The bearing of each flight line shall be within 5 degrees of the specified compass direction, and adjacent lines shall be within 5 degrees of parallel.

On all broken lines, two new exposures shall overlap with corresponding prints of the old section. No flight strips shall consist of fewer than eight exposures. Reflights shall be centered over areas where follow-up coverage is required.

5. *Overlap*

Forward print overlap (along the line of flight) shall average 60 percent, with a maximum of 65 percent and a minimum of 55 percent. Sidelap (between adjacent strips) should average 30 percent and fall within a range of 15 to 45 percent.

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[9] *Technical expressions used here are defined in the glossary of photogrammetric terms, p. 35.*

6. *Print alignment*

Excessive crab or drift will not be tolerated in any flight line, because it reduces the image area susceptible to effective stereoscopic viewing. For any three consecutive photographs, improper alignment shall not reduce the effective area to less than 90 percent of the print width.

7. *Tilt*

Vertical exposures are required for this project. Negatives will not be accepted if the photographic tilt exceeds 4 degrees for a single exposure or averages more than 1 degree for the entire area.

8. *Season of photography*

Photographic flights must be strictly limited to the periods specified in the bid invitation to produce desired tonal contrasts between different tree species. Exposures will not be accepted when the ground is covered by snow or flood waters (fig. 8).

9. *Time of day*

For effective photo interpretation, objects pictured should have well-defined, but not excessively long shadows. Therefore, exposures shall be limited to a photographic day beginning at least 3 hours after sunrise and ending at least 3 hours before sunset. Photographs taken under a high overcast or including numerous cloud shadows will not be accepted (fig. 9).

10. *Photographic film*

Only fresh, fine-grained aerial film having a low shrink base shall be used for this project. Maximum shrinkage after developing and drying shall not exceed 2½ parts per thousand when the film is dried in an oven for 7 days at a temperature

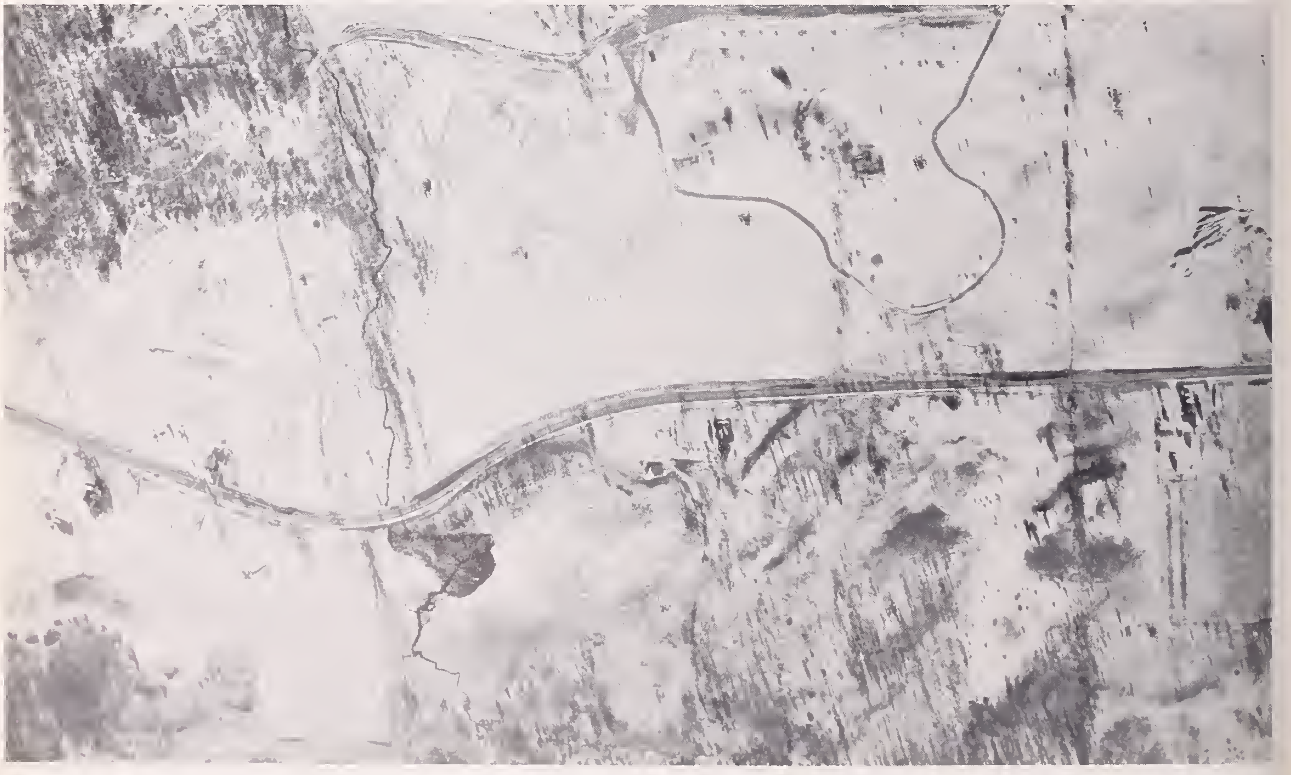

FIGURE 8. — Illustration of snow cover on an aerial photograph taken in northern United States. Dormant-season photography is rarely preferred by foresters, because of long tree shadows and the lack of foliage on deciduous plants. Scale: 550 feet per inch. (Courtesy of Abrams Aerial Survey Corporation.)

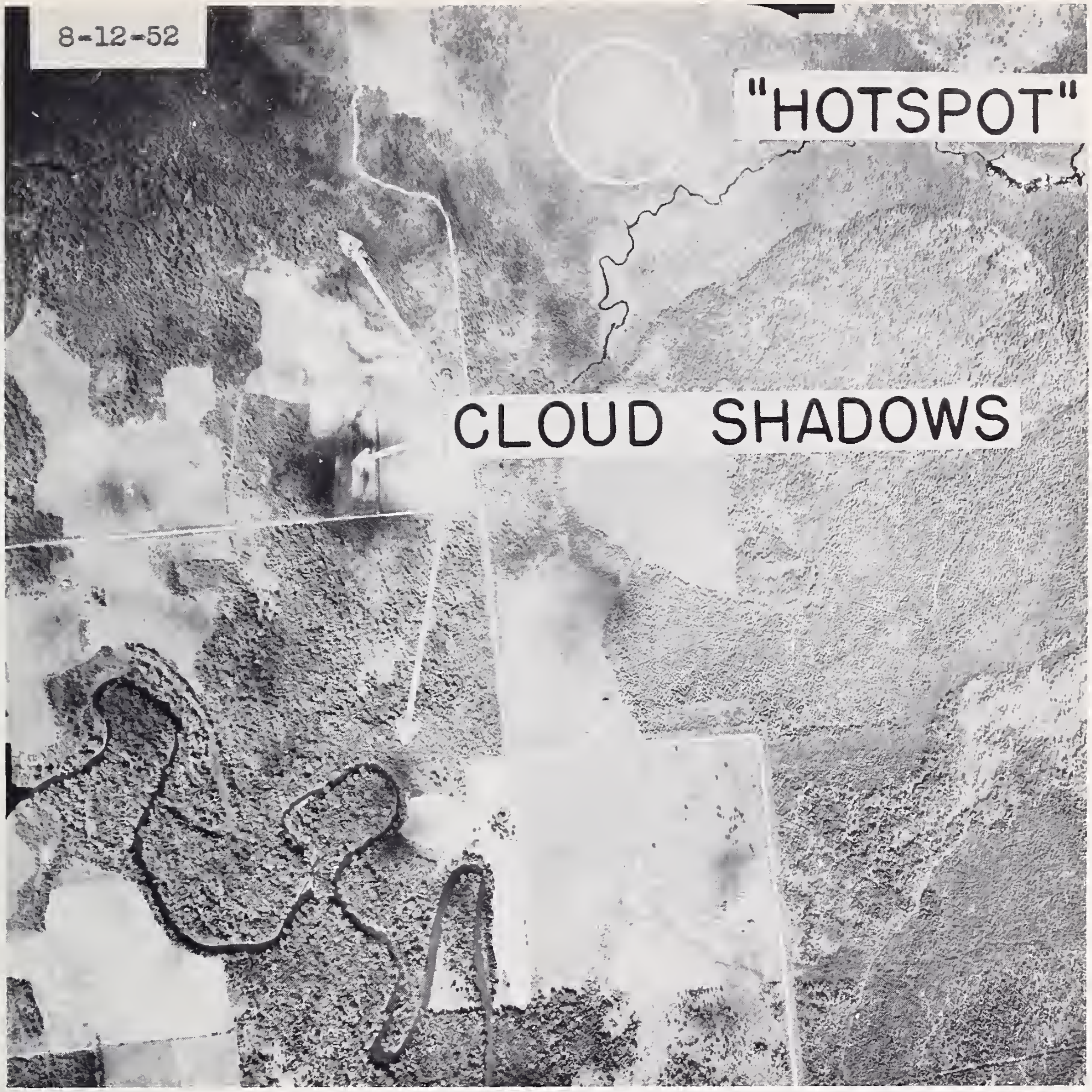

FIGURE 9. — Cloud shadows represent serious photographic defects, and their frequent occurrence may result in rejection of an entire flight line. Note the additional presence of a hotspot. Photo scale: 1:11,300.

of 120 degrees Fahrenheit. A 10-foot leader shall be attached to each end of the film roll before development. There shall be no buckle in the splice, and the leader shall have the same direction of curl as the film.

11. *Aerial camera specifications*

A single-lens aerial mapping camera having a negative format of 9- by 9-inches shall be used for this project. The platen against which the film is flattened at the instant of exposure shall not depart from a true plane by more than ± 0.0005 inch. The shutter shall be a between-the-lens type with variable aperture settings, and provision shall be made for holding the shutter leaves open during laboratory tests.

Lenses wih 6-inch focal lengths[10] shall have the following characteristics (fig. 10):

a. Focal length of 153 ± 3.0 mm.
b. Usable angular field of at least 90 degrees.
c. Minimum resolving power of 15 lines per mm.
d. Maximum tangential distortion of 0.015 mm.

It shall be possible to place a photographic plate in the camera focal plane. In addition, the focal plane shall be accessible from the rear to permit the viewing of objects directly through the camera lens. Removal of parts for this purpose shall not disturb calibrated relationships between lens, fiducial marks, and focal plane.

Minus-blue or other filters shall have anti-vignetting, metallic coatings. The two surfaces of the filter shall be within 10 seconds of arc of true parallel. Filters shall be of high optical quality to avoid reduction of image resolution.

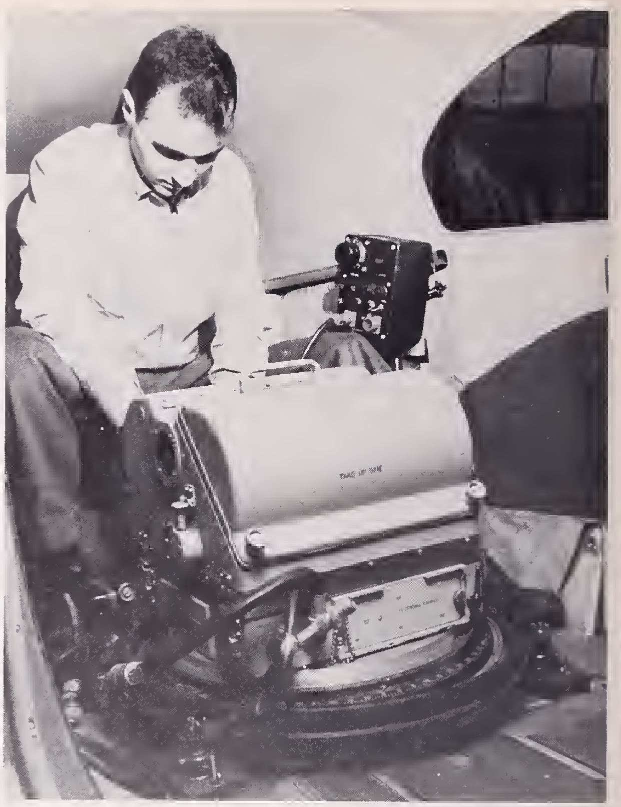

FIGURE 10. — Obtaining high-quality aerial photography requires both experienced personnel and modern equipment. The Fairchild "T-12" aerial camera shown here takes 9- by 9-inch exposures through a 6-inch Planigon, distortion-free lens. The small instrument attached to the aircraft wall is an intervalometer for controlling the time lapse between exposures. (Courtesy of Abrams Aerial Survey Corporation.)

SECTION III — FILM PROCESSING AND PRINTING

1. *Processing and drying film and prints*

Care shall be exercised in developing, fixing, and washing to insure uniform density and fine-grain quality of negatives and prints. Prints may be dried on blotters or screen-type frames, provided no weighting is used. Any mechanical drying processes used must incur no greater differential distortion than if the prints were dried by natural air circulation.

2. *Contact prints*

Contact prints from the vertical negatives shall be printed on double-weight, semi-matte paper with the degree of contrast specified by the purchaser. All prints shall be trimmed and unmasked.

3 *Photographic paper*

The purchaser shall have the privilege of selecting the type and grade of photographic paper to be used (8) (fig. 11). To minimize shrinkage, the grain of the paper shall be perpendicular to the length of the negative roll. For commercial-grade, double-weight paper, the average shrinkage difference, measured in any two directions after developing and drying, shall not exceed 4 parts per thousand.

4. *Quality of negatives and prints*

Negatives and prints shall be free from stains, scratches, or other blemishes. Medium-density negatives are desired, so that moderate exposure times will produce quality prints without loss of detail or contrast. Extremely "thin" or "dense" negatives will not be accepted. Prints shall have uniform color and density, with sufficient contrast to show all images on the negatives in sharp detail. Exposures that include such interpretation defects as hotspots, clouds, cloud shadows, snow, or static marks may be rejected.

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[10] *Similar requirements are commonly specified for cameras with other focal lengths.*

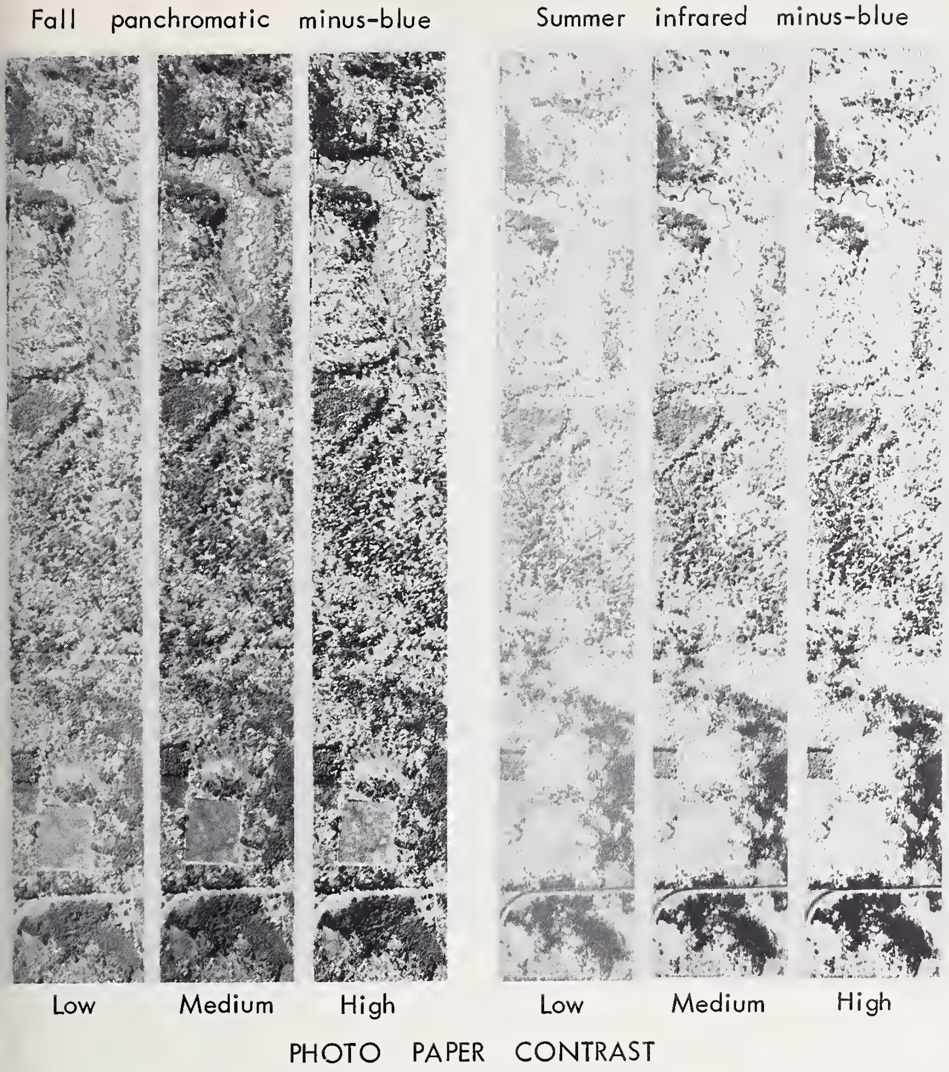

FIGURE 11. — Effects of different photo paper contrasts upon tonal rendition of forest cover types. Photography is of the same ground area in northern Minnesota and was flown at a scale of 1:15,840. (Courtesy of Mark Hurd Aerial Surveys, Inc.)

5. *Indexing and editing*

Each negative shall be marked clearly with the project symbol, film roll number, and exposure number (e.g., XYZ - 21 - 1) as well as the date of photography (e.g., 10-15-60). In addition, the first and last negative in each flight strip shall carry the scale and time of day exposed (fig. 12).

Photo indexes for the project shall be prepared *after* all negatives (and resulting prints) have been annotated. Images shall be carefully matched for assembly, and indexes shall be printed on double-weight, semi-matte paper at a scale of 1 inch per mile. Each index sheet shall have white margins and show all project boundaries. A complete title and description of the project, along with a graphic bar scale, shall also be shown.

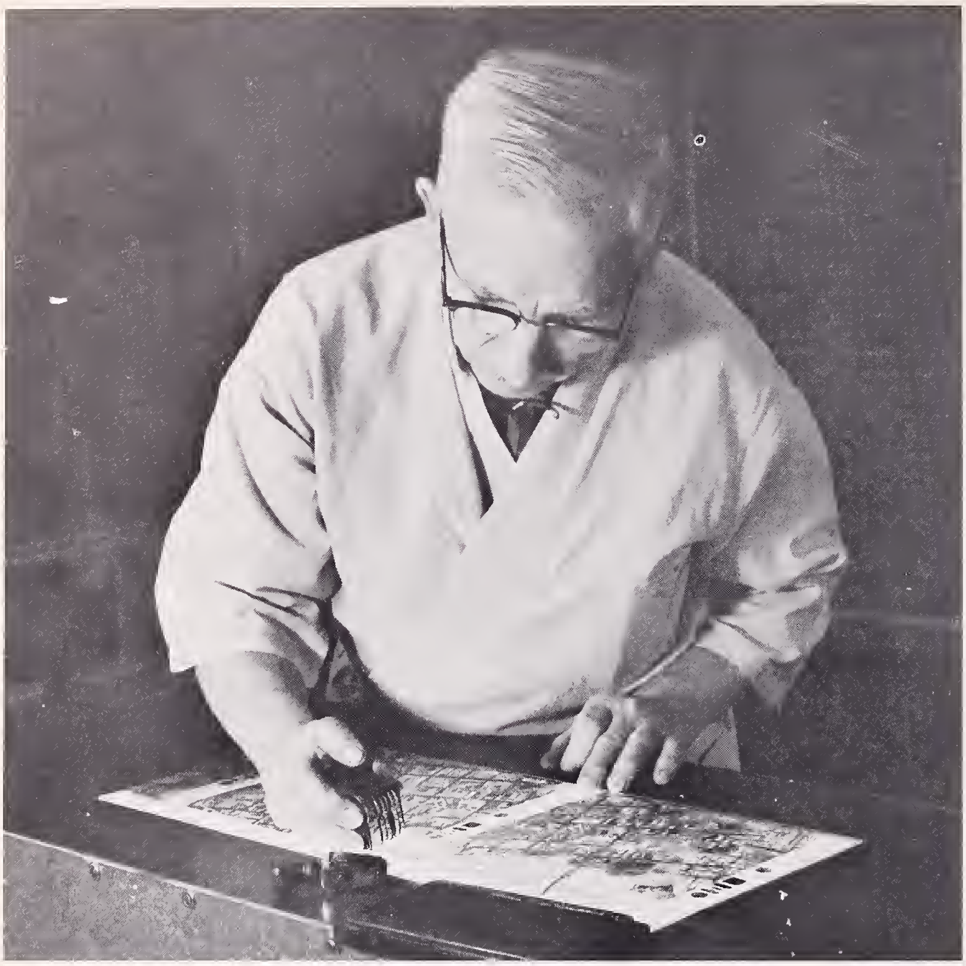

Figure 12. — Indexing and titling a roll of 9- by 9-inch negatives over a light table. This arrangement is also useful for inspecting negatives after contact prints have been made. (Courtesy of Abrams Aerial Survey Corporation.)

INSPECTING THE FINISHED PRODUCT

After a photographic survey is completed, it is customary for a representative of the purchaser to make a technical inspection of all prints, index sheets, and negatives. If the project was awarded to a reputable aerial survey firm at the beginning, the inspection and official acceptance of materials become a mere formality. In other instances, however, careful scrutiny may be required to determine whether the photography meets the standards set forth in the contract specifications (*4*).

Infrequent purchasers of aerial photography may have difficulty in evaluating the finished product, for acceptance or rejection of photographic flights often requires checks of such items as film titling, overlap, scale, and print quality. As a means of translating technical specifications into guides for the neophyte inspector, some type of itemized inspection form may prove useful (figs. 13 and 14).

A separate inspection checklist should be used for each flight line. Wherever applicable, blanks are filled in by entering photo exposure numbers. The inspector should be equipped with a complete set of flight maps, engineer's scale, protractor, and pocket stereoscope. Although the checklist is largely self-explanatory, major headings are discussed in the following sections.

TABLE 5. — *Conversion ratios for determining the average scale of aerial photographs*[1]

Scale conversion ratios when flight map scales (R. F.) are:					Aerial photo scale (R. F.)
1:250,000	1:125,000	1:62,500	1:31,680	1:24,000	
35.7	17.8	8.9	4.52	3.43	1: 7,000
33.3	16.7	8.3	4.22	3.20	1: 7,500
31.2	15.6	7.8	3.96	3.00	1: 8,000
29.4	14.7	7.4	3.73	2.82	1: 8,500
27.8	13.9	6.9	3.52	2.67	1: 9,000
26.3	13.2	6.6	3.33	2.53	1: 9,500
25.0	12.5	6.2	3.17	2.40	1:10,000
23.8	11.9	6.0	3.02	2.28	1:10,500
22.7	11.4	5.7	2.88	2.18	1:11,000
21.7	10.9	5.4	2.75	2.09	1:11,500
20.8	10.4	5.2	2.64	2.00	1:12,000
20.0	10.0	5.0	2.53	1.92	1:12,500
19.2	9.6	4.8	2.44	1.85	1:13,000
18.5	9.2	4.6	2.35	1.78	1:13,500
17.8	8.9	4.5	2.26	1.71	1:14,000
17.2	8.6	4.3	2.18	1.66	1:14,500
16.7	8.3	4.2	2.11	1.60	1:15,000
16.1	8.1	4.0	2.04	1.55	1:15,500
15.6	7.8	3.9	1.98	1.50	1:16,000
15.2	7.6	3.8	1.92	1.45	1:16,500
14.7	7.4	3.7	1.86	1.41	1:17,000
14.3	7.1	3.6	1.81	1.37	1:17,500
13.9	6.9	3.5	1.76	1.33	1:18,000
13.5	6.7	3.4	1.71	1.30	1:18,500
13.1	6.6	3.3	1.67	1.26	1:19,000
12.8	6.4	3.2	1.62	1.23	1:19,500
12.5	6.2	3.1	1.58	1.20	1:20,000
12.2	6.1	3.0	1.54	1.17	1:20,500

---

[1] *To use the table, several contact prints should be lapped in mosaic fashion. Measure distance between two points easily recognized on photos and flight map. With a photo distance of 18.8 inches and a map distance of 2.0 inches, ratio is 9.4. Assuming a flight map scale of 1:125,000, this ratio is interpolated above as representing a photo-scale of approximately 1:13,250.*

INSPECTION CHECKLIST

Place of inspection St. Paul, Minn. Inspector G. A. & M. M. Date 2-22-61

Area or project Jones County Flight line 12 Roll 6 Exposures 1 to 194

Altitude (MSL) 11,200 ft. Date flown 10-8-60 Time of day 1015 to 1104 CST

I. Film titles and symbols

Prints not dated Date illegible on 149, 150, 166

Project roll, or exposure not shown All correct

Scale & time not shown - first & last exposures Scale missing - 194

II. Flight line orientation and overlap

Line position or bearing incorrect O.K. - Deviation avg. 3 degrees

Forward overlap excessive 132, 133 Deficient None

Deficient lap at break in line No breaks At end of line O.K.

Sidelap excessive None Deficient None

Improper print alignment All acceptable Tilt None apparent

III. Scale checks - flight map scale of: 1:125,000

Map distance	Photo distance	Ratio	Photo scale (Table 5
4.6"	35.9"	7.8	1:16,000
5.3"	42.9"	8.1	1:15,500

IV. Print quality - check negatives in uncertain cases

Print detail blurred 46, 47, 48, 49

Chemical stains or blemishes None

Excessive contrast None Insufficient contrast 48, 49

Clouds or cloud shadows Minor Long image shadows None excessive

Hotspots None Excessive snow cover None

Floodwaters None Smoke or smog None

V. Recommendations

( ) Acceptance of entire flight line

(X) Conditional acceptance Correct titling as shown in I.

( ) Rejection - reflights necessary for exposures ______ to ______

FIGURE 13. — A complete inspection checklist provides a valuable record of corrective measures needed on each fight line.

Minnesota Aerial Photo Committee

AERIAL PHOTOGRAPHY CONTRACT INSPECTION REPORT

Project______________________ Inspector______________
Contractor____________________ Line No.______ Report Date______

Photo No. range	Deviations from contract specifications noted						
	Endlap	Sidelap	Crab exceeding 5°	Alignment		Tilt	Scale
	Photo: %	Photo: %		Flight line	Stereo triplicate		

Average endlap for line__________%
Average sidelap (with line_____) ________%
Average scale______________
Quality of photography in line______________________________
____
Titling____
____
Remarks____
____
RECOMMENDATIONS:_____________________________________

FIGURE 14. — An inspection report form.

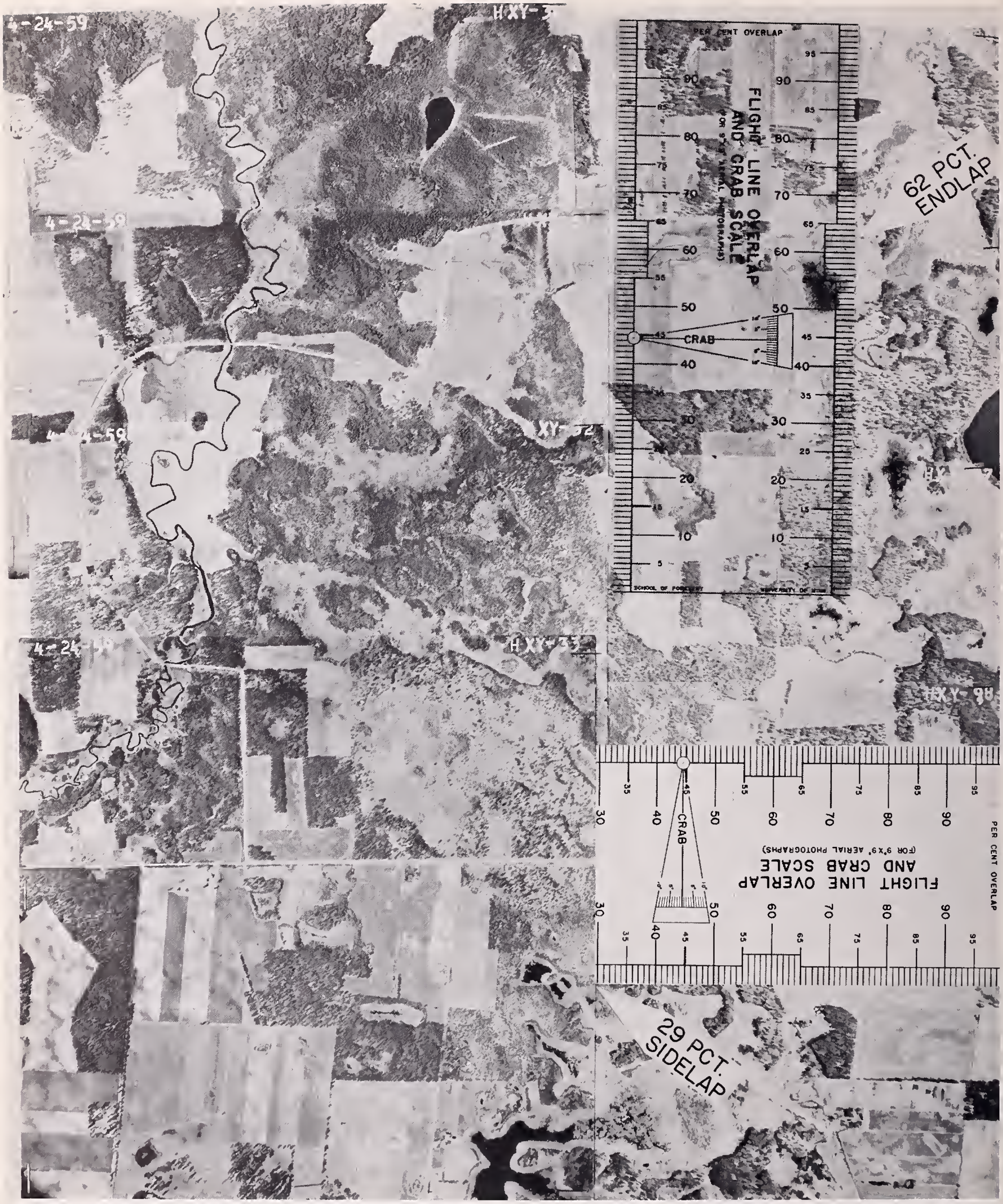

FIGURE 15. — Use of a special scale for measuring overlap and sidelap on two adjacent flight lines. Average overlap shown is 62 percent; sidelap averages 29 percent. (Courtesy of Mark Hurd Aerial Surveys, Inc.)

Film titles and symbols. — All prints should be dated in the upper left corner; project, roll, and exposure numbers should be shown in the upper right corner of each photograph. Nominal photo scale, as 1:15,840, and local standard time are ordinarily placed at the top center of the first and last exposures in each flight line, as well as on broken lines.

Flight-line orientation and overlap. — The center of the photographic flightstrip should be within a specified distance of the position plotted on original flight maps. Maximum deviation is usually set at 25 percent of the mean sidelap distance. The inspector should also check to make sure that the compass bearing of each flight line is within 5 degrees of the specified direction and that adjacent lines are within 5 degrees of parallel. Print overlap (along the line of flight) and sidelap (between adjacent lines) can be most efficiently checked by means of a special scale as shown in figure 15. A reproduction of this device appears inside the back cover of this report (9).

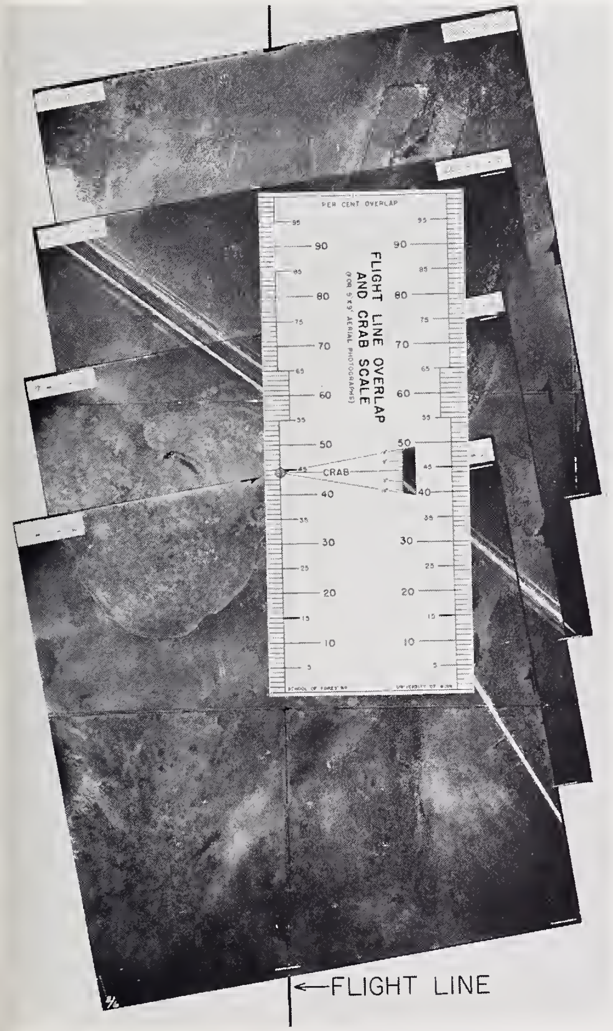
PER CENT OVERLAP
FLIGHT LINE OVERLAP AND CRAB SCALE
(FOR 9x9 AERIAL PHOTOGRAPHS)
90
80
70
60
50
CRAB
40
30
20
10
←FLIGHT LINE

FIGURE 16. — Four overlapping photographs that are "crabbed" or skewed with respect to the line-of-flight. The deviation shown averages about 9 degrees.

Print alignment. — Improper alignment refers to the presence of crab or drift along the line of flight, and it results in a stair-stepped or skewed pattern of overlapping prints. To make sure that not more than 10 percent of the overlap area is affected, checks of crab and drift (figs. 16 and 17) can be made as illustrated in figures 15 and 16 (with the same scale used to measure overlap and sidelap).

Tilt. — Photographic tilt results when the camera lens-axis is not perpendicular to the ground at the moment of exposure. It is most commonly encountered on prints near the ends of flight lines where exposures are made as the aircraft banks into a turn for the next strip. It is difficult to detect a small degree of tilt, but excessive amounts are quite evident on photographs of flat terrain having rectangular land subdivisions. In such instances, the oblique camera view results in an apparent convergence of grid patterns and parallel lines (fig. 18).

Scale checks. — Because of the time required, photo-scale checks are seldom made for individual prints. Instead, 10 or more overlapping prints are selected from each flight line for a check of the average scale across an expanded geographic transect. After the prints have been taped down in mosiac fashion, the distance between two points should be accurately measured (fig. 19). By computing a simple ratio between the photo measurement and the corresponding distance on the flight map, average print scale can be quickly read from table 5. After allowance for variations in local relief, this average should be within ± 5 percent of the specified scale.

Print quality. — This is usually the most difficult item for the new inspector to evaluate because of the lack of standards or criteria of comparison. Heavy reliance must be placed on subjective judgment in deciding whether a given photographic de-

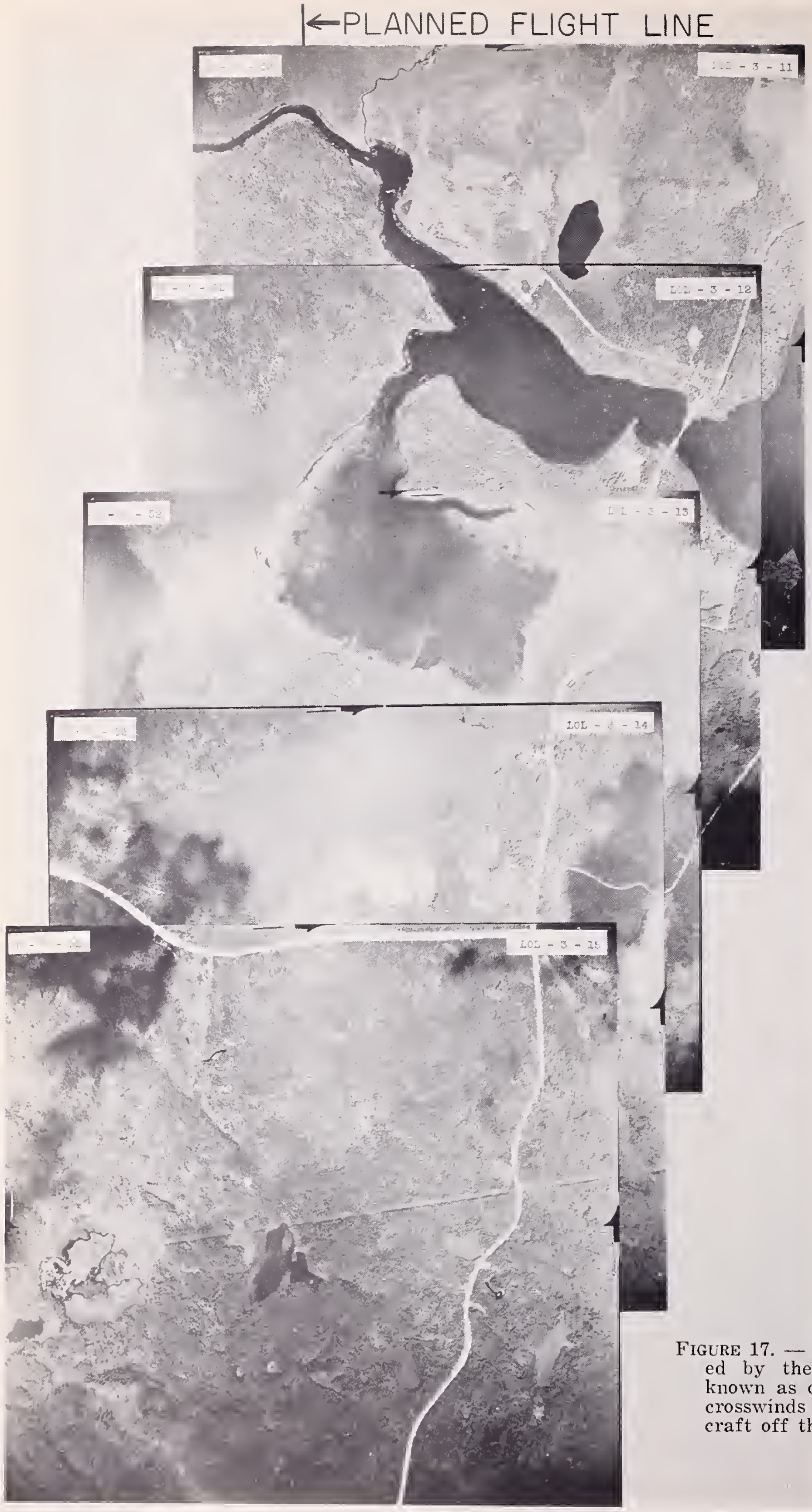

FIGURE 17. — The stair-stepped pattern formed by these five overlapping prints is known as drift. It is commonly caused by crosswinds that force the photographic aircraft off the planned flight course.

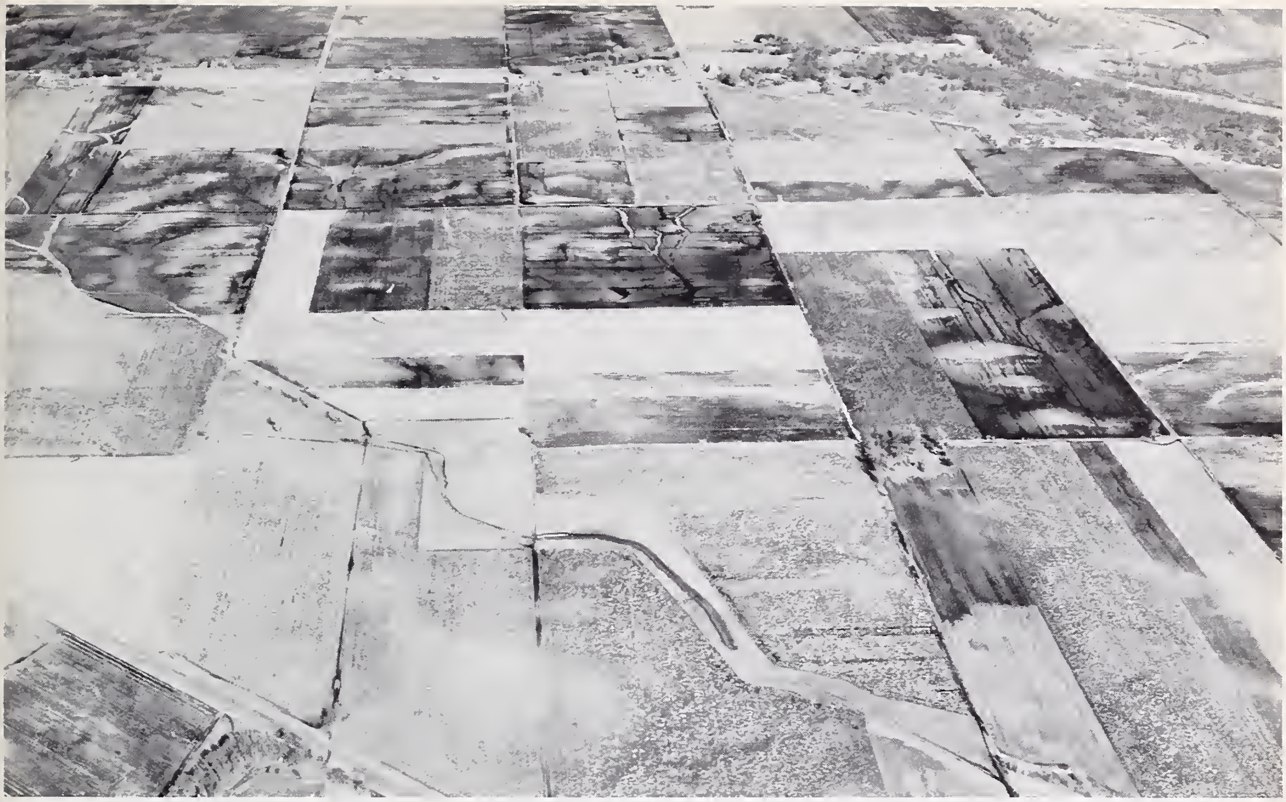

FIGURE 18. — In excessively tilted photographs, rectangular land subdivisions are distorted into asymmetrical shapes. The photograph shown here is actually a low oblique having a tilt of 15 to 20 degrees from the vertical. (Coutesy of Abrams Aerial Survey Corporation.)

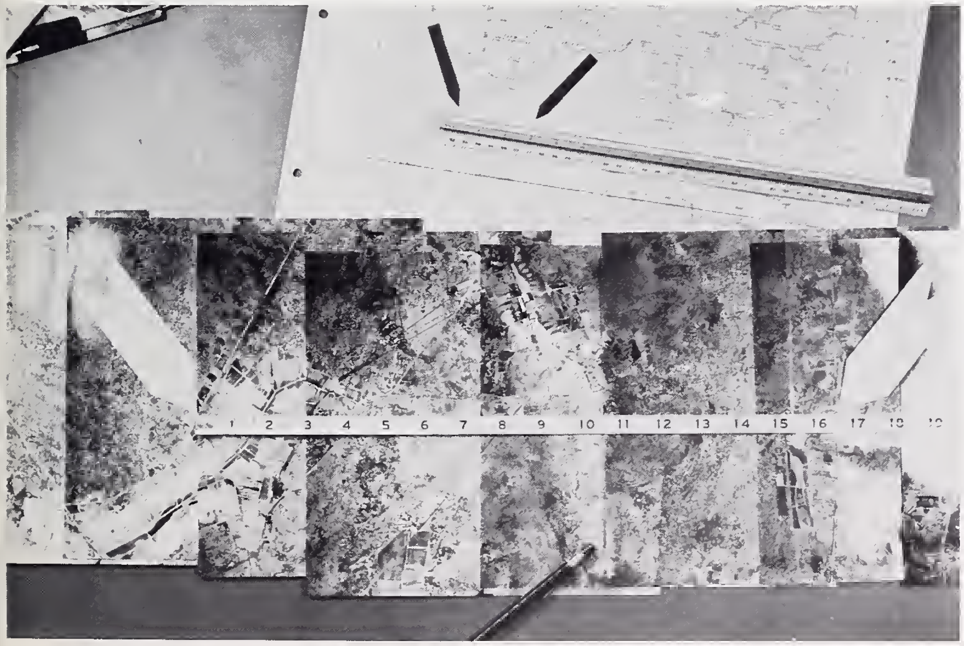

FIGURE 19. Checking the average photoscale across a series of overlapping prints. The ratio of photo distance to corresponding flight map distance (indicated by the two sets of arrows) is converted to a representative fraction by reference to table 5.

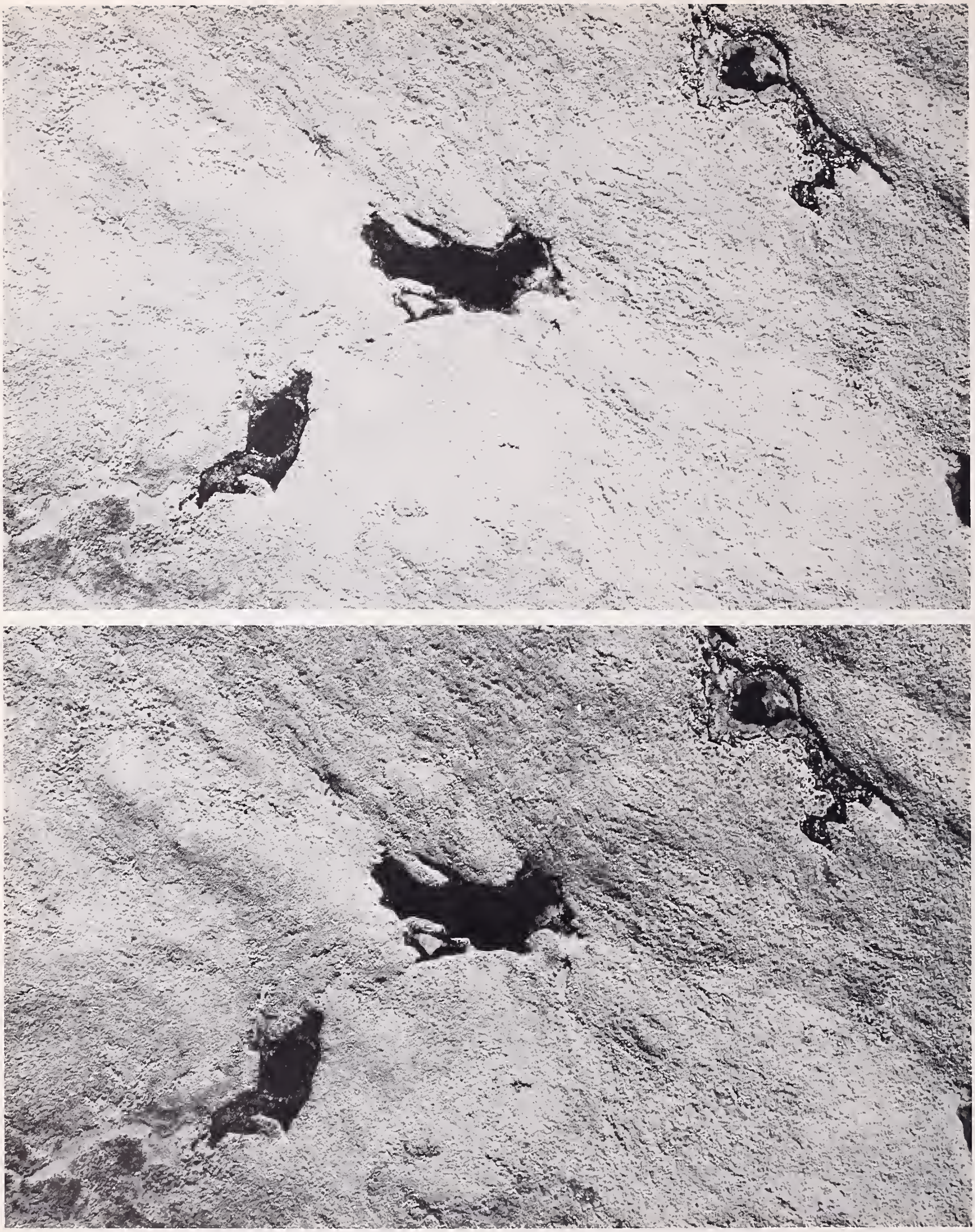

FIGURE 20. — Two prints made from the same negative on identical photographic paper. The washed-out center of the upper photo is attributed to an overexposed negative. In the lower print, detail was improved by "dodging," a printing technique that regulates the amount of light passing through the negative to the photographic paper. (Courtesy of Abrams Aerial Survey Corporation.)

fect constitutes a reasonable basis for rejection. Some of the "defects" cited under this section of the checklist may be of minor importance for certain photo interpretation projects. Where it is suspected that long image shadows are due to early morning or late afternoon flights, a check can be made by noting the time of photography on the first and last exposures in each line.

Although the original exposures may be of high quality, carelessness in printing may produce photographs with poor contrast, stains, or blurred detail. For this reason film negatives should be available for inspection over a light table (fig. 12). Special techniques in printing will often produce high-quality photographs even when negatives have poor density characteristics (fig. 20).

Recommendations. — The inspector should be constantly aware that a reputable contractor is his best ally in checking photographic materials. Aerial survey firms are usually more than willing to correct obvious photographic deficiencies, for a satisfied clientele is their best form of advertisement. At the same time, it shoud be recognized that it is unrealistic to demand absolute perfection on every detail specified in the contract. The summing up of all objectionable points should be tempered with sound judgment and cognizance of the contractor's efforts before an entire flight line is rejected.

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APPENDIX: GLOSSARY OF PHOTOGRAMMETRIC TERMS[11]

Air base (photogrammetry): The line joining two aerial camera stations. (MPI)

Altitude: Height above a datum. The datum is usually mean sea level. (MPI)

Angle of coverage: The apex angle of the cone of rays passing through the front nodal point of a lens. *Normal-angle lens* — a lens having an angle of coverage up to 75°; *wide-angle lens* — a lens having an angle of coverage 75° to 100°; *ultra wide-angle lens* — a lens having an angle of coverage greater than 100°. (MP)

Aperture, relative: The ratio of the equivalent focal length to the diameter of the entrance "pupil" of a photographic lens. Expressed "f:4.5," etc. Also called "f-number," "stop," "aperture stop," "diaphragm stop," "speed." (MPI)

Base, film: A thin, flexible, transparent sheet of cellulose nitrate, acetate, or similar material which is coated with a light-sensitive emulsion and used for taking photographs. (MPI)

Base, photo: The distance between the principal points of two adjacent prints of a series of vertical aerial photographs. It is usually measured on one print after transferring the principal point of the other print. (MPI)

Camera calibration: The determination of the focal length, the lens distortion in the focal plane, and the location of the principal point with respect to the fiducial marks. The settings of the fiducial marks and the positioning of the lens are ordinarily considered as "adjustments," although they are sometimes performed during the calibration process. In a multiple-lens camera, the calibration also includes the determination of the angles between the component units. (MPI)

Camera magazine: The removable part of a camera in which the unexposed and exposed portions of film are contained. (MPI)

Camera station: The point in space, in the air or on the ground, occupied by the camera lens at the moment of exposure. Also called the "exposure station." In aerial photography the camera station is called the "air station." (MPI)

Contact print: A print made from a negative or a diapositive in direct contact with sensitized material. (MPI)

Contrast, negative and printing: The difference between the greatest and least density. (The contrast of photographic materials is not synonymous with gamma. The latter rating does not include area of underexposure or overexposure, while a true contrast rating must consider the total range of densities.) (MPI)

Contrast, subject: The difference in light intensity between the brightest highlights and the deepest shadow.

Coverage: The ground area represented on aerial photographs, photomosaics or maps. (MPI)

Crab: 1. *(Aerial photography)* — The condition caused by failure to orient the camera with respect to the track of the airplane, indicated in vertical photography by the sides of the photographs not being parallel to the principal-point base line. See *drift.*
2. (Air navigation) — any turning of an airplane which causes its longitudinal axis to vary from the track of the plane. (MPI)

Datum: A reference element, such as a line or plane, in relation to which the positions of other elements are determined. Also called the "reference plane" or "datum plane." (MPI)

Density: The comparative amount of silver deposited by exposure and development in a given area. It is expressed in terms of the percentage of light passing through the area. (MPI)

Displacement, relief: The difference in the position of a point above or below the datum, with respect to the datum position of that point, owing to the perspective of an aerial photograph. Relief displacement is radial from a point on the photograph corresponding to the ground position vertically beneath the camera. In vertical photography relief displacement is radial from the principal point of the photograph. (MPI)

Dodging: The process of holding back light from certain areas of the sensitized paper in making a print, in order to avoid overprinting those areas. In projection printing it is accomplished by inserting an opaque medium of proper shape and size between the lens and the easel, and in contact printing either by varying the illumination in given areas of the negative or by inserting translucent or opaque paper between the light source and the negative. Dodging may also be performed automatically by means of specially designed electronic or fluorescent printers. (MPI)

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[11] *Source of the majority of terms:* Manual of Photogrammetry (1), *and the* Manual of Photographic Interpretation (2), *by permission of the American Society of Photogrammetry, 1515 Mass. Ave., Washington, D. C. These terms are identified, respectively as (MP and MPI). Terms without further identification are those of the authors — all others are numerically referred to Literature Cited.*

Drift: 1. (Air navigation) — The horizontal displacement of an aircraft, under the action of the wind, from the track it would have followed in still air.
2. (Aerial photography) — Sometimes used to indicate a special condition of crab wherein the photographer has continued to make exposures oriented to the predetermined line of flight while the airplane has drifted from that line. (MPI)

Effective area: For any aerial photograph that is one of a series in a flight strip, that central part of the photograph delimited by the bisectors of overlaps with adjacent photographs. On a vertical photograph, all images within the effective area have less displacement than their conjugate images on adjacent photographs. (MPI)

Emulsion: A suspension of light-sensitive silver salt, usually silver chloride or silver bromide, in a colloidal medium, usually gelatin, used for coating photographic films, plates, or paper. (MPI)

Fading: The loss of part or all of an image owing to incomplete fixing or washing, etc. (MPI)

Ferrotype: To burnish by squeegeeing while wet upon a japanned sheet of iron or stainless plate and allowing to dry; this produces a harder, glossier surface on the photographic print. (MPI)

Fiducial marks: Index marks, rigidly connected with the camera lens through the camera body, which form images on the negative. The marks are adjusted so that the intersection of lines drawn between opposite fiducial marks defines the principal point. (MPI)

Filter: A transparent material used in the optical path of a camera lens to absorb a certain portion of the spectrum and prevent its reaching the sensitized photographic film. (MPI)

Focal length, equivalent: The distance measured along the lens axis from the rear nodal point to the plane of best average definition over the entire field used in the aerial camera. (In general usage, the term also applies to the distance from the rear nodal point to the plane of best axial definition, but in photogrammetry this meaning is rarely used and will not be understood unless the term is accompanied by a qualifying phrase.) (MPI)

Focal plane (aerial photography): The plan (perpendicular to the axis of the lens) in which images of points in the object field of the lens are focused. (MPI)

Fog: A darkening of negatives or prints by a deposit of silver which does not form a part of the image. Fog tends to increase density and decrease contrast. It may be caused by exposure to unwanted light, exposure to air during development, forced development, impure chemicals, etc. (MPI)

Glossy print: Print made on photographic paper with a shiny surface. (MPI)

Hotspot (sunspot): The destruction of fine image detail on a portion of a wide-angle aerial photograph. Due to the absence of shadows and by halation near the prolongation of a line from the sun through the exposure station (7).

Index, photo: An index map made by assembling the individual photographs into their proper relative positions and copying the assembly photographically at a reduced scale. (MPI)

Line, flight: A line drawn on a map or chart to represent the track over which an aircraft has been flown or is to fly. The line connecting the principal points of vertical aerial photographs. (MPI)

Magazine: A container for protecting and holding film while the camera is in operation. It is usually detachable from the camera so that a new magazine or film roll may be introduced during flight. (MPI)

Map, flight: A map on which are indicated the desired lines of flight and/or positions of exposure for the taking of aerial photographs, or the map on which are plotted, after photography, selected air stations and the tracks between them. (MPI)

Marks, static: Marks on a negative caused by discharges of static electricity, particularly when the unexposed negatives are handled rapidly under dry conditions. The marks are of many different types. Some are easily recognized as branching or tree-like static, and some are less distinctive, more or less sharply defined dots. (MPI)

Matte print: Print made on photographic paper with a dull finish; more suitable for pencil or ink annotations than a glossy print. (MPI)

Nadir, photograph: That point at which a vertical line through the perspective center of the camera lens pierces the plane of the photograph. Also referred to as the "nadir point." (MPI)

Negative, dense: A negative of which all parts have high opacity; the result of overexposure. (MPI)

Negative titling: Information (e.g., sortie number, camera, date, height, etc.) recorded on the negative for identification. (MPI)

Overdevelopment: The result of permitting film or paper to remain in the developer too long, resulting in excessive contrast or fog. (MPI)

Overexposure: The result of too much light being permitted to act on a light-sensitive material, with either too great a lens aperture or too slow a shutter speed or both. Results in excessive image density. (MPI)

Overlap (photography): Amount by which one photograph overlaps the area covered by another, customarily expressed as a percentage. The overlap between aerial photographs in the same flight is distinguished as the *end lap*, and the overlap between photographs in adjacent parallel flights is called the *side lap*. (MP)

Photogrammetry: The science or art of obtaining reliable measurements by means of photography. (MPI)

Photographic interpretation (photo interpretation): The act of examining photographic images for the purpose of identifying objects and judging their significance. (MPI)

Plate, pressure: A flat plate, usually of metal but frequently of glass or other substance which, by means of mechanical force, presses the film into contact with the focal plane plate of the camera. (MPI)

Print, semi-matte: A print intermediate in glossiness between a matte and a glossy print. (MPI)

Processing: The operation necessary to produce negatives, diapositives, or prints from exposed film, plates, or papers. (MPI)

Representative fraction (R.F.): The relation between map or photo distance and ground distance, expressed as a fraction (1/25,000) or often as a ratio (1:25,000) (1 inch on map = 25,000 inches on the ground). Also called "scale." (MPI)

Resolution: The ability of the entire photographic system, including lens, exposure, processing, and other factors, to render a sharply defined image. It is expressed in terms of lines per millimeter recorded by a particular film under specified conditions. (MPI)

Resolving power: A mathematical expression of lens definition, usually stated as the maximum number of lines per millimeter that can be resolved (that is, seen as separate lines) in the image. (MPI)

Run: The line followed by a photographic aircraft in making a photo strip. (MPI)

Sensitivity, color: The sensitivity of a photographic emulsion to light of various wave lengths. (MPI)

Shrinkage, differential: The difference in unit contraction along the grain structure of the material as compared to the unit contraction across the grain structure; frequently applied to photographic film and papers and to mapping papers in general. (MPI)

Shutter, between-the-lens: A shutter located between the lens elements of a camera and usually consisting of thin metal leaves which open and close or revolve to make the exposure. (MPI)

Soft: A term applied to a print or negative of relatively low contrast; also applied to a picture which is not sharply focused. (MPI)

Shutter, focal plane: A shutter located near the focal plane and consisting of a curtain with a slot which is pulled across the focal plane to make the exposure. (MPI)

Strip: Any number of photos taken along a photo flight line, usually at an approximately constant altitude. (MPI)

Tilt: The angle between the optical axis of the camera and the vertical. (MPI)

Tone: Each distinguishable shade variation from black to white. (MPI)

Underdevelopment: Insufficient development, due to developing either for too short a time or in a weakened developer, or occasionally at too low a temperature. (MPI)

Underexposure: The result of insufficient light being allowed to pass through the lens to produce all the tones of an image; or of sufficient light being allowed to pass for too short a period of time. (MPI)

Vignetting filter: A filter which gradually decreases in density from the center toward the edges. It is used in certain cases in photography or printing processes to produce a photograph of uniform density. (MPI)

Weight, double-: Heavy-weight photographic paper. (MPI)

Weight, single-: Light-weight photographic paper. (MPI)

SOME RECENT STATION PAPERS

LAKE STATES FOREST EXPERIMENT STATION

European Pine Shoot Moth Damage as Related to Red Pine Growth, by H. J. Heikkenen and W. E. Miller. Sta. Paper 83, 12 pp., illus. 1960.

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Evaluating the Growth Potential of Aspen Lands in Northern Minnesota, by R. O. Strothmann. Sta. Paper 86, 20 pp., illus. 1960.

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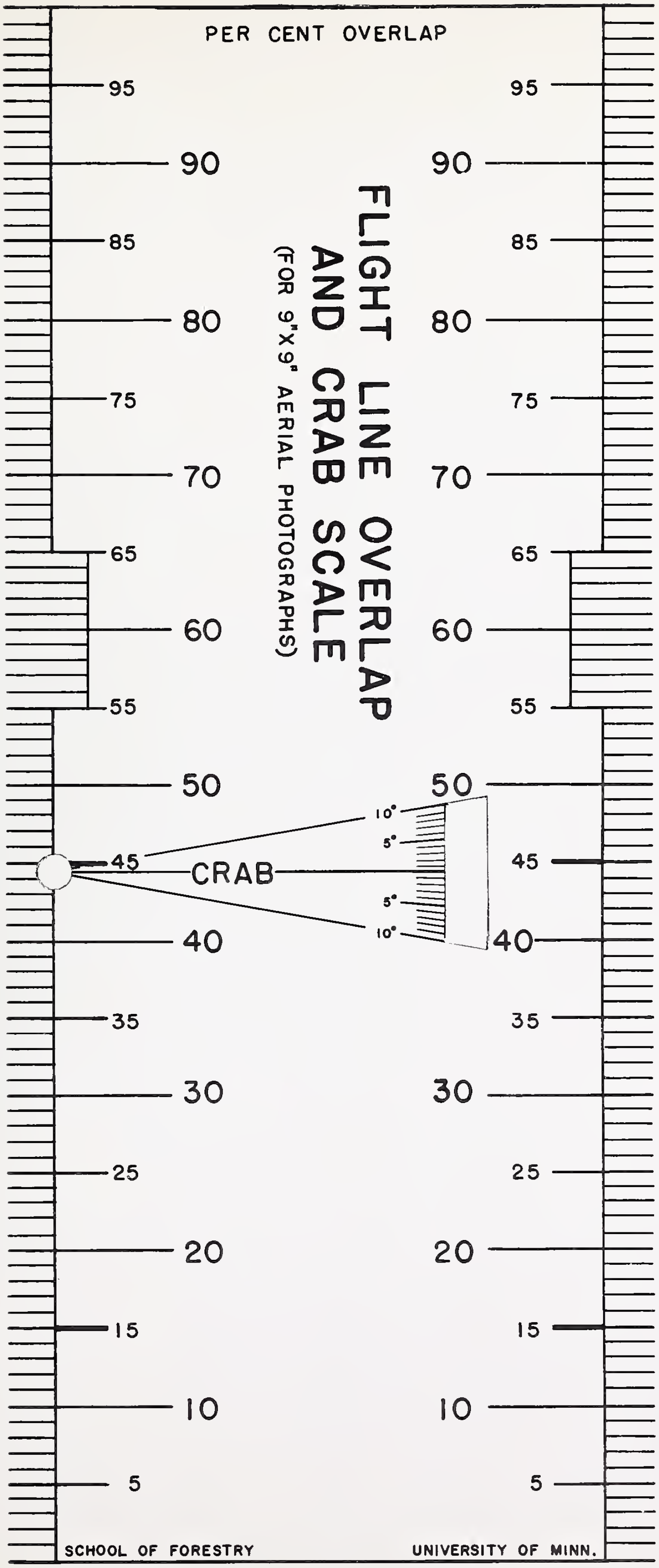
PER CENT OVERLAP
FLIGHT LINE OVERLAP
AND CRAB SCALE
(FOR 9"X9" AERIAL PHOTOGRAPHS)
CRAB
10°
5°
5°
10°
SCHOOL OF FORESTRY
UNIVERSITY OF MINN.

WOOD · WATER · FORAGE · WILDLIFE · RECREATION

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